UNCLASSIFIED

AD NUMBER
AD354893
CLASSIFICATION CHANGES
TO: unclassified
FROM: secret
LIMITATION CHANGES
TO: Approved for public release, distribution unlimited
FROM: Controlling DoD Organization. Army Ordnance Corps, Redstone Arsenal, AL.
AUTHORITY
CRD D/A ltr, 24 Aug 1981; CRD D/A ltr, 24 Aug 1981

THIS PAGE IS UNCLASSIFIED

Best
Available
Copy

SECRET [redacted]

TECHNICAL REPORT NO. 5

LEADTIMES FOR DEVELOPMENT OF GUIDED MISSILES

LABORATORIES

NEW JERSEY

MENLO PARK, CALIFORNIA

SECRET

STANFORD RESEARCH INSTITUTE

MENLO PARK, CALIF.

This doc... Espionage Laws, ... Its transmission or ... manner to an unauthorized person is prohibited by law.

October 1958

Technical Report 5

LEADTIMES FOR DEVELOPMENT OF GUIDED MISSILES

(8)

By: Pierce H. Gaver, Jr. and Orin J. Mead

S R I Proj[redacted] *IU-2351-2*

Prepared for:

REDSTONE ARSENAL OF THE U.S. ARMY ORDNANCE CORPS
HUNTSVILLE, ALABAMA
EVANS SIGNAL LABORATORY OF THE U.S. ARMY SIGNAL ENGINEERING LABORATORIES
FORT MONMOUTH, NEW JERSEY

[redacted] *Contract* [redacted] *DA-04-200-ORD-442* [redacted] *DA-04-200-506-ORD-710, with the San Francisco Ordnance District, entitled "Economic Recommendations Concerning the Development of the Army Ordnance Surface-to-Air Missile Systems."*

Approved:

William L. White

WILLIAM L. WHITE, ASSISTANT DIRECTOR OF ECONOMICS RESEARCH

Paul J. Lovewell

PAUL J. LOVEWELL, DIRECTOR OF ECONOMICS RESEARCH

Copy No. ...... of 50

05516 SECRET

SECRET

PREFACE

This study was [illegible] performed as a part of a continuing analysis of weapons programs by Sta[illegible]nford Research Institute for the Army Ordnance Corps and the Evans Signa[illegible]l Laboratory of the Signal Corps Engineering Laboratories under Cont[illegible]acts DA-04-200-ORD-[illegible]42 and DA-04-200-506-ORD-710. The over-all research [illegible] effort is devoted to the study of Army air defense systems and their av[illegible]ability, capability, and cost.

This research [illegible] was done in the Economics Division of Stanford Research Institute under th[illegible] supervision of William L. White, Assistant Director of Economics Resea[illegible]ch, Defense Studies, and Richard B. Foster, Manager, Weapons Program Re[illegible]search.

An oral presen[illegible]tation of the research was given to the Ordnance-Signal Corps Steering Comm[illegible]ttee in February 1958.

Special recogn[illegible]tion is due Dr. Thomas G. Belden, Albert Shapero, Jack I. Cooper, an[illegible] Virginia Olesen for their contributions and guidance during the cour[illegible] of the research.

SECRET

SECRET

TABLE OF CONTENTS

SECRET

Table of Contents (Continued)

LIST OF FIGURES

List of Figures (Continued)

LIST OF TABLES

Section I

INTRODUCTION

Background

A comprehensive method for analysis and evaluation of weapons systems has been developed by Stanford Research Institute to give better information to decision-makers concerned with allocating national resources among future weapons systems. The method for analysis and evaluation can be summarized in ten steps:

1. Establish a strategic framework outlining the boundaries of intercontinental thermonuclear war and the place of the air defense system therein.

2. Analyze the target system to be defended, assigning measures of value to the components. These value measures are the primary criteria of effectiveness of the weapons systems.

3. Analyze on a dynamic basis the capabilities of the expected or designated enemy as a threat to the target system.

4. Determine the environment in which attack and defense operate, including those factors relevant to plans and execution. This step is particularly important when environmental systems for air defense weapons are being evaluated.

5. Define and describe the weapons systems under study, determining functions and parameters of the systems. Establish and identify the variations, official and unofficial, of the system.

6. Analyze the operational availability of the defined systems under alternative states of national urgency.

7. Perform a cost analysis on the weapons systems, including unit costs, initial investment program costs distributed as fiscal year expenditures, and annual operating costs of achieving various schedules at various force levels for various states of national urgency.

8. Establish the capabilities of the weapons systems in an operational environment on a dynamic basis and match these capabilities at each point in time against the estimated future potentials of the threat.

9. Determine, through analysis of the factors involved, the operational (such as reliability) and logistical (such as schedule slippages) degradation of the weapons systems.

10. Determine the effectiveness of the air defense systems as they fit into our defense posture at various force levels under various states of urgency, utilizing the measures of value established.

Finally, make use of successive approximations so that the strategic framework is constantly modified, countering changes in enemy strategy.

The method seeks a complete statement of the problem to provide perspective for an evaluation, and it treats all elements -threat, target defense measures, and air defense weapons--as varying over time.

The research reported on in this study is a part of Step 6--Availability Analysis--and is specifically concerned with leadtime.

Normally, Stanford Research Institute's availability analyses deal with the time between the end of feasibility study and the deployment of some quantity of units in operational condition. These leadtime studies have gone beyond the leadtimes involved in weapons hardware, and have been concerned also with the associated personnel training, operational site acquisition and construction, support activities, and management activities (contracts, decision dates, funding, etc.).

Several techniques and methods for evaluating availability estimates are in development and use at Stanford Research Institute. They will be reported at a later date. Technical evaluations are made of the state of the art of all components of a particular weapon system to help determine technical feasibility of that weapon system and its schedule. Concurrently, a detailed analysis is made of the master schedule for a weapon system program so as to isolate any internal inconsistencies. Techniques also include an examination of the planning factors and assumed conditions which underlie an estimated completion date. Costs are correlated with the master schedule to determine annual expenditures needed to attain that schedule

The research reported on herein is background material contributing to comprehensive and specific analyses. Since the primary objective of the research on air defense has been directed toward providing organized facts and evaluations to decision-makers, it was deemed appropriate to examine in some detail those official documents that presented data to strategic decision-makers at the Army Staff and Department of Defense level. This study examines the historical record of the data reported on thirty-one missile systems in the Annual Guided Missile Progress Reports (DOD form DD-613, entitled R&D Project Card) and the data reported by each of the services to DOD and listed in the DOD Guided Missile Program Table. The study views the adequacy of these documents for providing a source of information for important strategic decisions.

Scope of Study

This paper is a part of these continuing efforts of Stanford Research Institute to evaluate the Army's air defense missile systems by extending availability research into five basic areas:

1. What is the definition of the phases of a weapon cycle, and how adequate are the definitions in current use toward establishing a rigorous system of reporting to insure comparability among all weapons systems?

2. How much time do the weapon cycle and its phases consume?

3. What are the errors in estimating the length of the weapon cycle and its phases?

4. What can be done to shorten the weapon cycle, and what data and techniques are required to control leadtime from research to operational status?

5. What is the relationship of dollar expenditures to the weapon cycle?

This paper provides background data in basic areas 2 and 3 ("How much time is required, and what are the errors of estimating?"), and indicates how this knowledge can be useful in evaluating missile programs. In addition, the study examines the data submitted on official reporting forms to determine the degree to which the data contained in these reports are adequate for use by strategic decision-makers.

This technical report specifically examines:

1. The actual leadtimes to operational status[1/] for nine United States missile systems, and the leadtimes to estimated

---

1 Time from project start to operational status. Project start does not necessarily correspond to the end of the feasibility study (normally the starting date of Stanford Research Institute leadtime studies).

operational status for an additional twenty-two United States missile systems (Section III).

2. The relationship between estimated and actual dates of operational availability for eight of the nine operational missile systems; also, the relationship between first estimates and the latest estimates for thirteen nonoperational missile systems (Section IV).

3. The changes in leadtime as a function of calendar year of start of project (Section V).

4. Time to the first production contract as a ratio of time from project start to operational status (Section VI).

5. The relationship of estimated and actual completion dates of operational availability to estimated and actual completion dates of research, development, test, and operational evaluation for the Army's family of missile systems (Section VII).

6. The series of estimates of completion dates for research, development, test, and operational evaluation for the Army's family of SAM systems: NIKE-AJAX, NIKE-HERCULES, HAWK, TALOS (land-based), and PLATO (Section VIII).

This report consists primarily of analyses of data in these areas. No attempt is made to assign causes for variation of leadtimes or causes for errors of estimate. However, to provide some guidance in the proper use of the statistics, it was necessary to present a general outline of the nature of errors and to raise questions or cautions in the use of the data.

Section II

SUMMARY

This technical report is an analysis of data on missile system leadtimes. The report does not purport to explain specifically--system by system--why leadtimes vary and estimating errors exist, nor does it pretend to categorize the estimating errors as "preventable" or "not preventable." The general causes of errors in estimating are discussed, but this report does not link specific cause and effect in the discussion of estimating errors. Nevertheless, much has been learned about the nature of the leadtime measurement problem. Following are the major observations drawn from this study.

1. Available leadtime data leave much to be desired in terms of accuracy of definition and consistency. This statement should not be interpreted as vitiating the conclusions of this report. It does mean, however, that it was not possible to get precise and consistent data because of the ambiguities of the definitions of specified events. Therefore the statistical results should be treated as approximate.

2. The leadtime for operational status of missile systems has averaged about eight to nine years. The nine missile systems which were operational in June 1957 averaged 8.7 years from project start to first unit in an operational status. The span of leadtimes was from about 6 to 11 years, with 78 percent of the nine systems falling in the 8- to 9-1/2-year bracket.

Using the latest estimates of operational availability, the average leadtime for twenty-two systems which are not yet operational is about the same as for the nine operational systems. However, the span is greater (4 to 19 years), and 82 percent of the systems fall in the 5- to 12-1/2-year bracket.

3. Estimates of leadtimes to operational availability have usually been optimistic. For the nine operational systems, the first estimates of operational availability were optimistic by 2 to 4-1/2 years (i.e., the estimated dates were sooner than the actual dates). Only 3 percent of all estimates up to the time of operational availability were pessimistic (estimated date later than actual date) by more than one-half year. The estimated time-to-go (that is, time from date of estimate to estimated operational availability) averaged about 65 percent of the actual time required; however, individual estimates varied widely from the average.

The thirteen systems which are not yet operational show a somewhat poorer estimating performance than the nine operational systems in terms of the "slippage" rate (rate of delay in years per year of the estimated operational availability date). However, no significant difference in the average slippage rate could be determined between the systems started prior to 1950 and those started after 1950.

4. The average of the latest estimates of leadtimes for missile systems initiated after 1950 is less than those for the pre-1950 missile systems. The average leadtime for systems started prior to 1950 is about 10-1/2 years, based on actual leadtimes for operational systems and mid-57 military service estimates for the not-yet-operational systems. For post-1950 systems, the average of mid-57 estimated leadtimes is about 7 years, or 3-1/2 years less than average leadtimes for the pre-1950 systems. If the estimating error data for the eight operational systems are used to compensate for the probable optimistic error in the estimates for the post-1950 systems, the compensated average leadtime would be about 9 years, or 1-1/2 years less than the pre-1950 systems.

5. For seven of the nine operational systems, one-half to three-quarters of the total leadtime was spent prior to the first production contract. For the nine operational systems, about 25 to 85 percent of total leadtime was spent prior to first production contract. Seven systems were grouped in the range from 50 to 75 percent. In terms of years, the range of times from first production contract to operational availability varied from about 1-1/2 to 6-1/2 years. Variation for the most closely grouped six systems was from about 3 to 4-1/2 years.

The maximum variation of estimated percentages of time spent prior to first production contract for eleven not-yet-operational systems for which data were available was about the same as for the nine operational systems. Nine of the eleven systems were fairly evenly distributed between 50 and 85 percent. In terms of years from first production contract to estimated operational availability, the variation was from about 1 to 7 years. Seven of the eleven systems are estimated to require from 2-1 2 to 3-1 2 years. Further delays in estimated operational availability dates may change this pattern

6. The data for eleven Army missile systems showed no marked time relationships between total leadtime and completion of activities in the R&D phase (i e. research development, test and operational evaluation). Although it is logical to suppose that time relationships do exist between completion of the various R&D activities and operational availability, no marked correlations were apparent in the data. Hence, knowledge of the estimated completion dates of R&D phases as reported by the military

services to DOD appears to be of little value in evaluating operational availability dates. Two reasons for the low correlation are probably (1) the time relationships are different from system to system, and (2) research, development, test, and operational evaluation are difficult to define in terms of a specific system.

7. For NIKE-AJAX, NIKE-HERCULES, and HAWK, estimates of completion dates for activities in the R&D phase (i.e., research, development, test, and operational evaluation) in general showed greater rates of change, or slippage, than estimates of operational availability. Examination of data for these three Army SAM systems suggests that the present reporting by the military services to DOD does not define R&D phase activities adequately for meaningful interpretation with respect to system definition. For example, it is probable that early estimates of the completion of R&D phase activities refer to the first configuration of the system to become operational. Some subsequent estimates probably refer to advanced configurations; hence, the estimated completion dates for the R&D phase activities show greater rates of delay than the estimated dates for operational availability of the first configuration.

8. The present system for reporting leadtime data is inadequate for planning and control purposes, particularly in R&D activities. This statement is based upon the discussions of Summary Statements Nos. 1, 5, 6, and 7

It is apparent that more thought and analysis must be given to reporting and controlling the leadtime parameters of R&D if substantial leadtime reductions are to be realized.

9. The data in this report, if employed judiciously with other more detailed system data, are useful for broad planning purposes until further analysis explains the cause-effect relationships. The reader is warned to use these data with caution because qualitative factors influence leadtime. The influence of these factors on the leadtime data has not been determined; hence there are limitations on the use of these data alone in reference to any single system. However, these data can provide a useful means for evaluating schedules when combined with other detailed system data

Section III

LENGTH OF LEADTIME FOR THIRTY-ONE UNITED STATES GUIDED MISSILE SYSTEMS

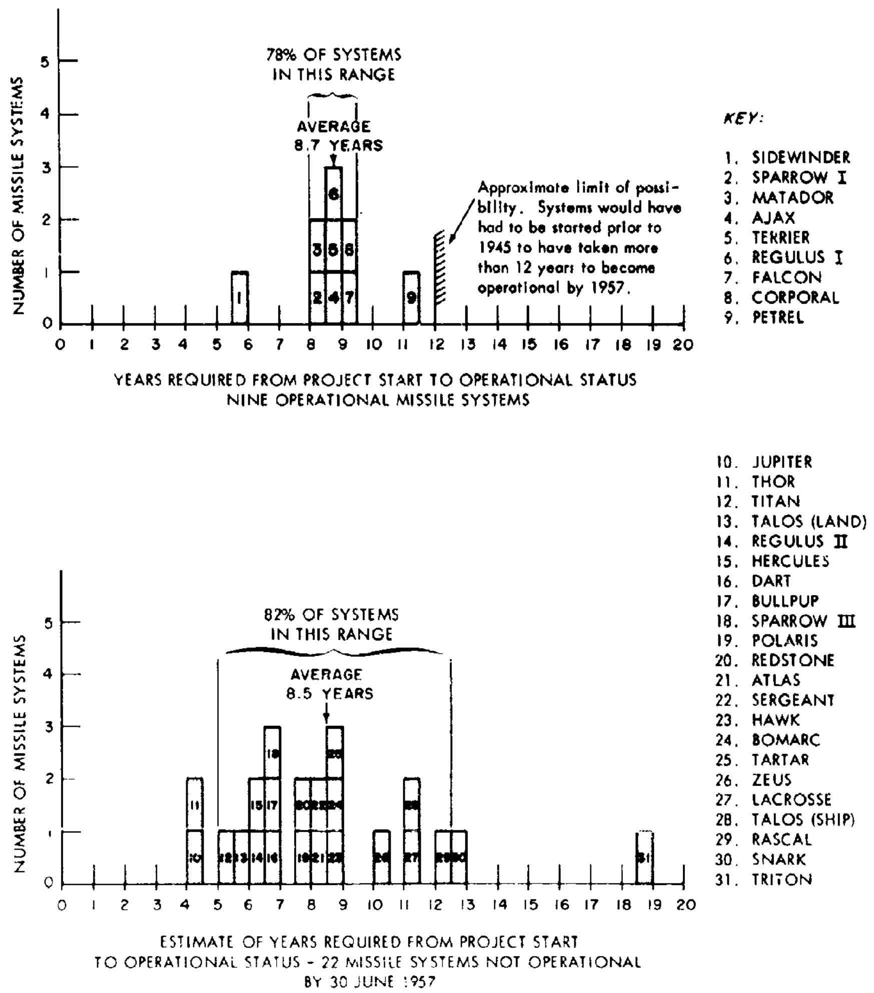
Figure 1 shows (1) the time spans of nine operational systems from project initiation to first operational availability, and (2) the estimated time spans of twenty-two not-yet-operational (or "nonoperational") guided missile systems. The dates used for the starts of the projects and actual and estimated operational availability come from two primary sources: (1) the Office of the Assistant Secretary of Defense, R&E, including the DOD Guided Missile Program Tables, and (2) the annual Guided Missile Progress Reports of the Army, Navy, and Air Force. (See Appendix Table A-1, column 2, for specific data references by missile system.)

The DOD Guided Missile Program Tables from which the data were obtained listed fifty-five systems; however, actual or estimated leadtimes could be calculated for only the thirty-one systems (shown in Table I and Figure 1) for which the dates of project initiation were given.

The thirty-one missile systems were classified into two groups, operational and nonoperational, as of 30 June 1957, in order to show similarities and differences between the actual leadtimes of operational systems and estimated leadtimes for systems which were not operational.

The nine operational systems required an average of 8.7 years from project initiation to operational availability (see Figure 1). Of the nine systems, seven systems (78 percent) are grouped in the interval from 8 to 9-1/2 years (1-1/2 years' variation). The extremes range from just under 6 years to more than 11 years, a variation of about 5-1/2 years.

According to the mid-57 estimates, the twenty-two nonoperational systems will require about the same average time to become operational (8.5 years) as the nine operational systems. However, the variation of estimated leadtimes is greater. As Figure 1 shows, the central 82 percent of the systems (eighteen systems) are estimated to require about 5 to 12-1/2 years (7-1/2 years' variation, where operational systems varied 1-1/2 years), and the extremes range from 4 to almost 19 years (about 15 years' variation, as against 5-1/2 years' variation for operational systems).



SOURCE Appendix Table A-1

FIG. 1

ACTUA' AND ESTIMATED LEADTIMES FOR NINE OPERATIONAL AN' '-TWO NONOPERATIONAL GUIDED MISSILE SYSTEMS

Table I

DOD GUIDED MISSILE PROGRAM TABLE (AS OF 30 JUNE 1957)
DATES OF EARLIEST OPERATIONAL AVAILABILITY
(Service Estimates)

Missile System	Service	Included in Analysis	Missile System	Service	Included in Analysis
SAM			ASM		
NIKE-AJAX	A	X	RASCAL (GAM-63)	AF	X
NIKE-HERCULES	A	X	BULLPUP (ASM-N-7)	N, AF	X
NIKE-ZEUS	A	X	GREEN QUAIL (GAM-72)	AF	-
TERRIER (SAM-N-7)	N (MC)	X	CORVUS (ASM-N-8)	N	-
ADV. TERRIER Bt-3	N	-	B-52 ASM (WS-138)	AF	-
ADV. TERRIER Btn (Nuc or HE)	N	-	B-58 POD	AF	-
ADV. TERRIER Ht-3	N	-			
TALOS (Ship) SAM-N-6b	N	X	AUM		
TALOS (Ship) SAM-N-6bl	N	-			
TALOS (Ship) SAM-N-6bw	N	-	PETREL (AUM-N-2)	N	X
TALOS (Ship) SAM-N-6bwl	N	.			
TALOS (Land) (6bl and 6bwl)	A	X	SSM		
BOMARC IM-99A	AF	X			
BOMARC IM-99B	AF	-	MATADOR (TM-61A) MSQ guidance	AF	X
TARTAR (SAM-N-)	N	X	MATADOR (TM-61C) Shanicle guidance	AF	-
HAWK (SAM-A-18)	A (MC)	X	MATADOR (TM-61B) Atran guidance	AF	-
PLATO	A	-	REGULUS I (SSM-N-8)	N	X
WIZARD (WS-222A)	AF	-	CORPORAL Type II (SSM-A-17)	A	X[2]
			REDSTONE (SSM-A-14)	A	X
AAM			LACROSSE (SSM-A-12)	A	X
			DART (SSM-A-23)	A	X
SPARROW I (AAM-N-2)	N	X	SERGEANT (SSM-A-27)	A	X
SPARROW III (AAM-N-6)	N	X	JUPITER	A	X
SPARROW X	N	-	THOR (SM-75)	AF	X
FALCON (GAR-1, 1D)	AF	X	REGULUS II (SSM-N-9)	N	X
FALCON (GAR-2, 2A)	AF	-	POLARIS (SSM-N-)	N	X
FALCON (GAR-3)	AF	-	TRITON (SSM-N-2)	N	X
FALCON (GAR-4)	AF	-	SNARK (SM-62)	AF	X
SIDEWINDER I (AAM-N-7)	N (MC)	X	ATLAS (SM-65)	AF	X
SIDEWINDER IA (AAM-N-7)	N (MC)	-	BULL GOOSE (SM-73)	AF	-
SIDEWINDER IA (GAR-8)	AF	-	TITAN (SM-68)	AF	X
Patrol Heavy Attack Defense	N	-			
EAGLE	N	-			

1 Earliest operational availability--the date when the first unit is equipped to have capability for action against the enemy except for IRBM's and ICBM's which are for beginning of Initial Operational Capability (IOC).

2 The analysis treats the CORPORAL E (Type I), which is very similar to Type II except for the operational availability dates.

Source: OSD, Asst. for R&E, October 1957.

Because the data for the twenty-two nonoperational systems consist of time durations from project start to estimated date of operational availability, they are different from data for the operational systems in two important respects:

1. Some of the twenty-two nonoperational systems will probably be cancelled prior to becoming operational. These unsuccessful systems quite possibly have an average of latest estimated leadtimes that is different from the average of those that will be successful.

2. As discussed in the next section of this report, estimates of future accomplishment have a strong tendency to be optimistic with respect to the actual accomplishment; hence, as these systems become operational, their actual leadtimes will probably be found to have been greater than the current estimates.

Because of these two important differences between actual and estimated leadtimes, it can be stated only that the twenty-two nonoperational systems are estimated to require about the same average length of time to become operational as the average length of time for the nine operational systems, and that the variation of the estimated leadtimes is much greater than the variation of actual leadtimes.

Section IV

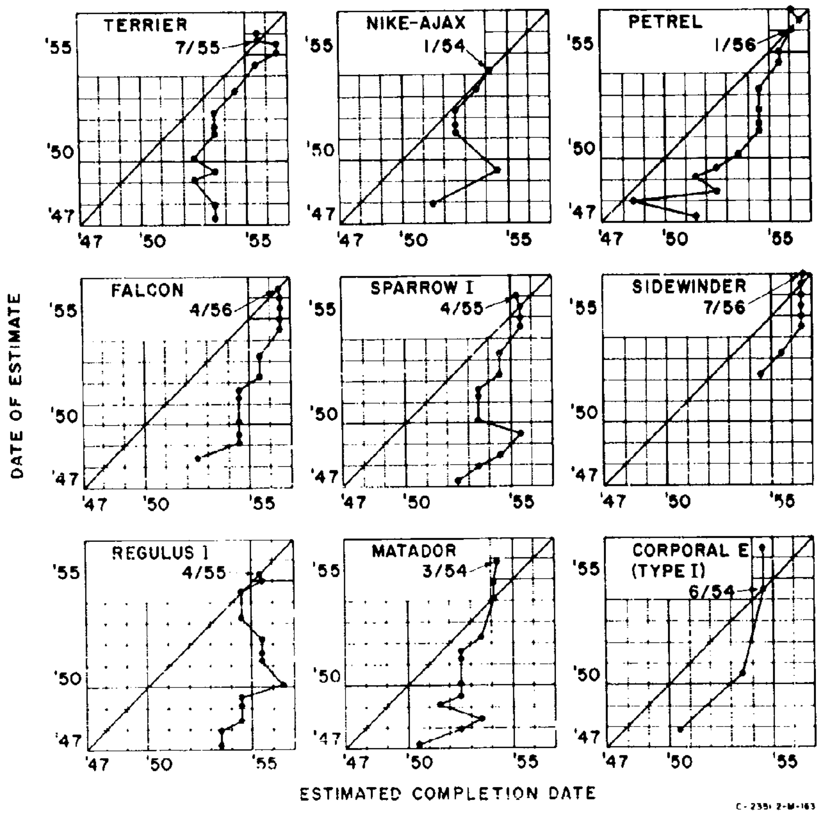
ERRORS OF ESTIMATE

Figure 2 illustrates the successive estimates of the date of first operational availability for nine guided missile systems which had become operational by mid-1957. The estimates are official estimates made by the three military services to the Department of Defense. (See Appendix B for explanation of the method of plotting Figure 2.)

In general, the plots for the nine systems have a similar pattern: the estimated completion dates tend to become progressively later with passage of time. The first reported estimates for the nine systems deviated from the actual dates by 2 to 4-1/2 years in an optimistic direction (i.e., estimated dates were sooner than actual dates). In the case of PETREL, one subsequent estimate was optimistic by 7-1/2 years. Only 3 percent of all the estimates made were pessimistic by more than a half year.

Individual estimates vary widely in their error. It must be emphasized that the term "error," as used in this report, refers to the time difference between estimated events and actual events regardless of cause; no blame is implied. Figure 3 was plotted to show the relationship between estimated and actual times-to-go (time from date of estimate to date of operational availability) for the eight operational systems for which several estimates were available (CORPORAL, with only two estimates available, was omitted). This figure shows that the estimated time-to-go averaged about 65 percent of the actual time-to-go. Stated in years, 6 years from operational availability, the average estimate was about 4 years; at 3 years to go, the average estimate was about 2 years. This means that there was about 2 years' average optimistic error at 6 years to go and about a year's at 3 years to go. The average optimistic errors in this figure are the vertical distances from the average estimate points to the "correct estimate line." The average optimistic error tended to be about 35 percent of the actual time-to-go. Note that these are averages. Individual estimates and errors vary widely from the averages, and the estimates for a single missile system can fall predominantly above or below the averages.

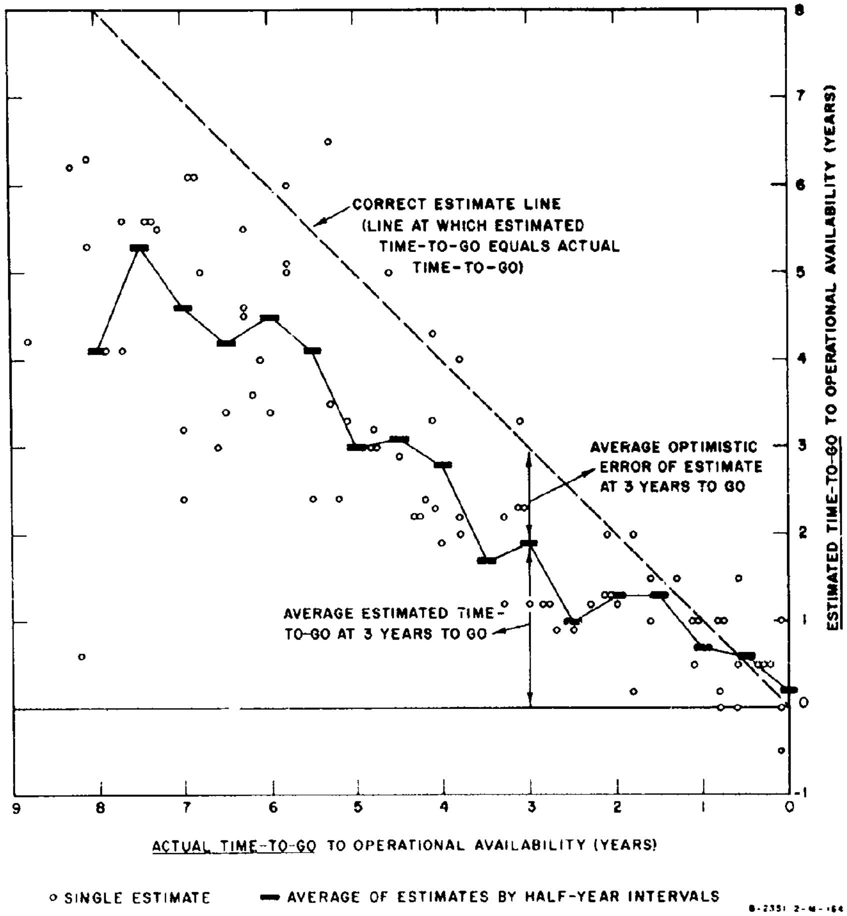
Unfortunately, the actual time-to-go is not known for future events and is therefore a poor reference against which to measure errors. Figure 4 was plotted from the orientation of the military planner, who must



SOURCE Appendix Table A-2 See Appendix B for method of plotting

FIG. 2

ESTIMATED COMPLETION DATES OF OPERATIONAL AVAILABILITY
FOR NINE OPERATIONAL GUIDED MISSILE SYSTEMS

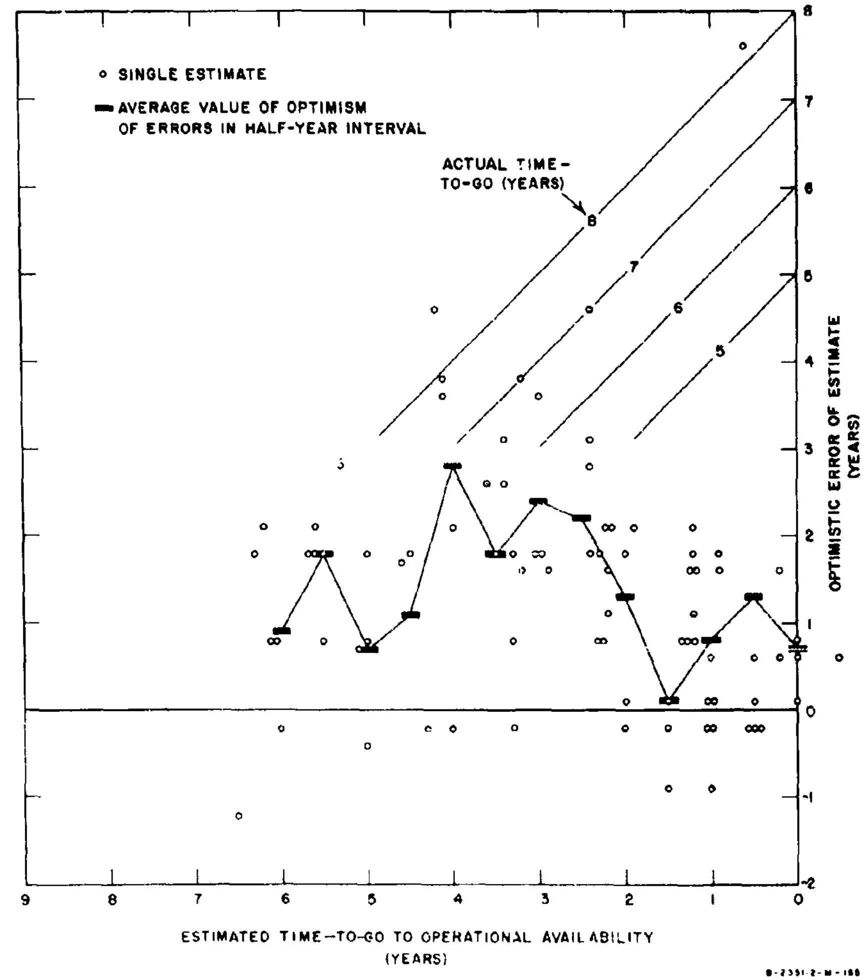


NOTE: Time-to-go is time from date of estimate to actual or estimated date of operational availability.

SOURCE: Appendix Table A-3

FIG. 3

ESTIMATED VS ACTUAL TIME-TO-GO TO OPERATIONAL AVAILABILITY
FOR EIGHT OPERATIONAL MISSILE SYSTEMS



NOTE Time-to-go is time from date of estimate to actual or estimated date of operational availability

SOURCE Appendix Table A - 3

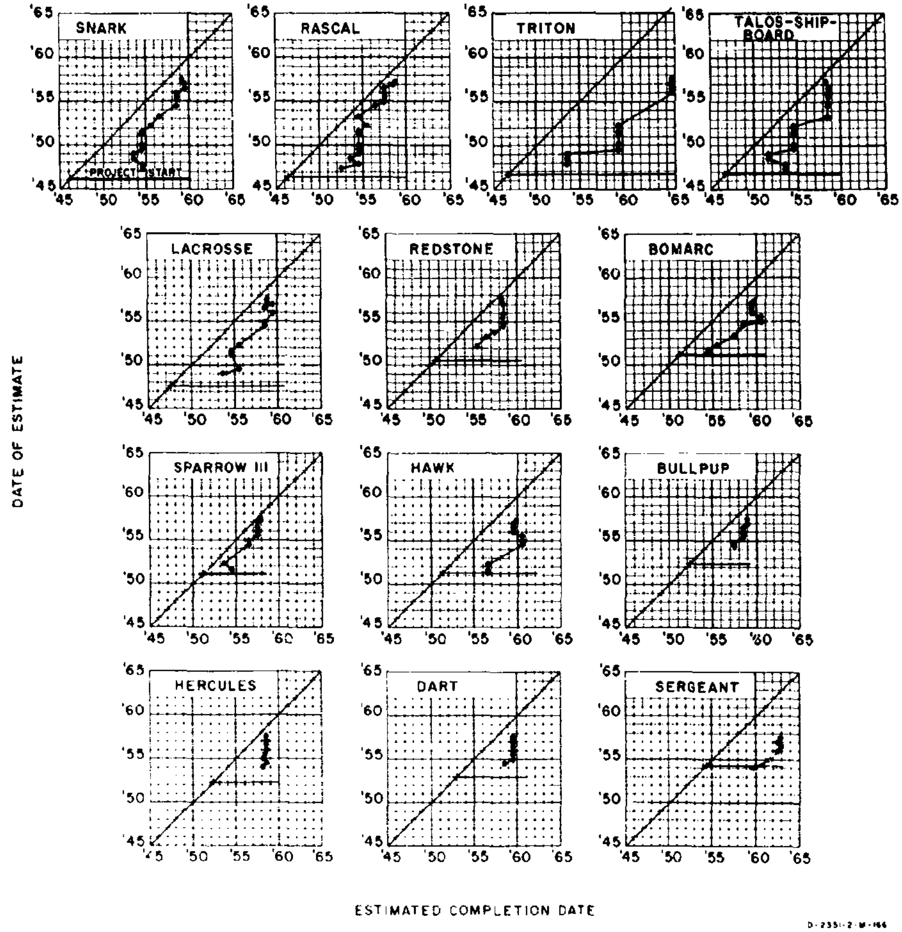
FIG. 4

OPTIMISTIC ERRORS VS ESTIMATED TIME-TO-GO TO OPERATIONAL AVAILABILITY FOR EIGHT OPERATIONAL MISSILE SYSTEMS work with estimated time-to-go. Figure 4 is derived from the same estimates as Figure 3, but shows optimistic errors plotted against estimated time-to-go. By visual inspection it can be seen that the average error of estimate was greatest (roughly 2 years optimistic) when the estimated time-to-go was 3 to 4 years. As might be expected, the average error decreased as the estimated time-to-go decreased below 3 years. However, the average error was also smaller (1 to 1-1/2 years) for estimates of 5 or 6 years to go. This seeming anomaly of greater accuracy for longer estimates can be explained by the limited range of actual times-to-go for the eight systems: all but five estimates were made when the actual time-to-go was less than 8 years. The effect is clear in Figure 4; the data are compressed into a triangle bounded, approximately, by the 8-year "actual time-to-go" line and the two axes. Some changes in Figure 4 can be anticipated if it is kept up to date as more systems become operational. For example, if SNARK, RASCAL, TALOS (shipboard), and LACROSSE become operational, the actual time-to-go boundary of the data points will move out from 8 to 8-1/2 years to about 11 or 12 years (or more) and numerous data points will be added with at least 4 to 6 years' error for estimates of 3 to 6 years time-to-go. As a result, the average error values will probably increase, particularly in the area from 3 or 4 to 7 years estimated time-to-go.

Figure 5 was plotted to show the history of estimates for thirteen of the twenty-two nonoperational guided missile systems in order to compare them to the history of estimates for the nine operational guided missile systems shown in Figure 2. The nonoperational systems which were not plotted (nine systems) had data for less than 3 years of estimates, which are not enough to establish definite patterns of estimating performance.

A cursory examination of the plots for nonoperational systems in Figure 5 shows a strong similarity to the plots for operational systems in Figure 2. In both cases, first estimated completion dates are optimistic by up to several years and subsequent estimated completion dates are later with passage of time.

Table II was prepared to show similarities or differences in the estimating performances for the operational systems and those for the nonoperational systems. The numerical measure used to describe estimating performance, illustrated in Figure 16 (in the appendix) is the average slippage rate (i.e., average rate of change of the estimated date of operational availability per calendar year). For operational systems, the slippage rate is determined by the first estimate and the actual operational availability date. For nonoperational systems, probable earliest and latest dates of operational availability are defined which establish



SOURCE: Appendix Table A-4

FIG. 5

ESTIMATED COMPLETION DATES OF OPERATIONAL AVAILABILITY FOR THIRTEEN NONOPERATIONAL GUIDED MISSILE SYSTEMS

Table II

RATES OF CHANGE OF ESTIMATED
FIRST OPERATIONAL AVAILABILITY DATE

Category 1--9 Operational Systems		
System	Project Start Date	Average Slippage Rate (year's delay per year)
PETREL	8/44	0.53
CORPORAL E	12/44	.60
AJAX	2/45	.44
MATADOR	2/46	.53
REGULUS I	6/46	.23
TERRIER	11/46	.25
SPARROW I	12/46	.35
FALCON	3/47	.50
SIDEWINDER	9/50	.47
Average		0.43

Category 2--5 Nonoperational Systems Started in 1946 and 1947			
System	Project Start Date	Average Slippage Rate (year's delay per year)	
		Probable Minimum	Probable Maximum
SNARK	2/46	0.39	0.49
RASCAL	5/46	.56	.62
TRITON	9/46	.68	.73
TALOS (Ship)	11/46	.44	.52
LACROSSE	7/47	.55	.63
Average		0.52	0.60

Category 3--8 Nonoperational Systems Started in 1950 or Later			
System	Project Start Date	Average Slippage Rate (year's delay per year)	
		Probable Minimum	Probable Maximum
REDSTONE	7/50	0.47	0.58
BOMARC	1/51	.63	.72
SPARROW III	1/51	.54	.61
HAWK	3/51	.39	.55
BULLPUP	4/52	.32	.54
HERCULES	4/52	.08	.13
DART	12/52	.20	.48
SERGEANT	1/54	.37	.55
Average		0.36	0.53

a probable minimum and maximum slippage rate. These probable earliest and latest dates are based on the error data of Figure 4. If these data for the operational systems hold true for the nonoperational systems, about 80 percent of the nonoperational systems will have operational availability dates falling between the derived earliest and latest dates. Appendix C gives the details of projecting the probable earliest and latest availability dates.

The data on average slippage rates are grouped into the three categories shown in Table II:

1. The nine operational systems.

2. The five nonoperational systems started in 1946 and 1947.

3. The eight nonoperational systems started in 1950 or later which have enough data to establish a slippage rate.

Within each category the average slippage rate varies substantially from one system to another. For the operational systems, the variation was from 0.23 to 0.60 year's delay per year. For the nonoperational systems, the variation was in about the same or a somewhat greater degree.

Table III is a summary of the averages of the slippage rates for the three categories and for combinations of the three. The following summary statements can be made with respect to Table III:

1. The nine operational systems (Category 1) show a smaller average slippage rate than the probable average of the thirteen nonoperational systems (Category 4) for which slippage rates can be established (0.43 versus the 0.43 to 0.56 average of probable minimum and maximum rates). In other words, the average slippage rate for operational systems can be expected to increase as more systems become operational.

2. The thirteen systems which were started prior to 1950 (Category 5) have a range of averages of probable minimum and maximum slippage rates (0.47 to 0.49) which fall within the range (0.39 to 0.52) for the post-1950 systems for which slippage rates can be established (Category 6). In short, slippage rates do not appear to be growing significantly better or worse with time

Table III

SUMMARY OF RATES OF CHANGE OF ESTIMATED OPERATIONAL AVAILABILITY DATES

No.	Category	Actual Average Rates of Change of Estimated Dates (year's delay per year)	Estimated Probable Average Rate of Change of Estimated Dates (year's delay per year)	
			Minimum	Maximum
1	9 operational systems	0.43		
2	5 nonoperational systems started in 1946 and 1947		0.52	0.60
3	8 nonoperational systems started in 1950 or later		0.38	0.53
4	13 nonoperational systems (categories 2 and 3)		0.43	0.56
5	8 operational systems[1] and 5 nonoperational systems started prior to 1950		0.47	0.49
6	1 operational system[1] and 8 nonoperational systems started in 1950 or after		0.39	0.52

1 SIDEWINDER which is operational, was started in 1950.

Section V

TREND OF LEADTIMES REQUIRED

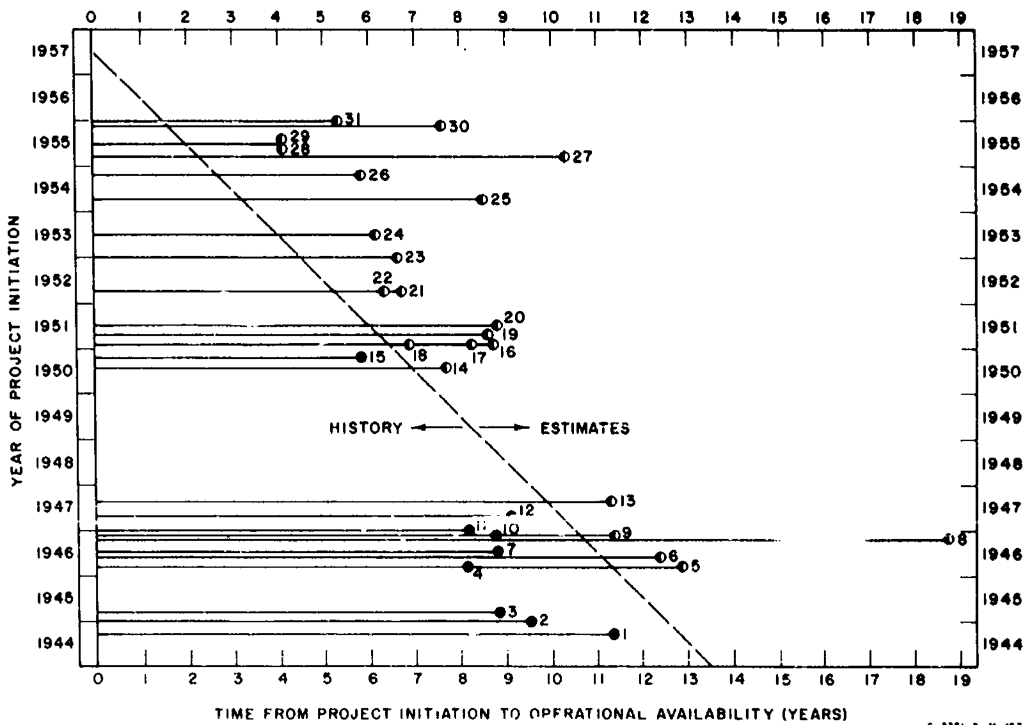
The actual and estimated leadtimes for the thirty-one guided missile systems are plotted in Figure 6 against the dates of initiation of the projects in order to show whether there are tendencies for later missile systems to require greater or less leadtime than earlier missile systems.

The sloping dashed line in Figure 6 represents mid-57. To its left are plotted actual leadtimes for the nine operational missile systems; to its right are plotted estimated leadtimes for the twenty-two nonoperational systems.

When operational and nonoperational systems are viewed together, it would appear that missile system developments started in 1950 or later will require less leadtime, on an average, than those started in 1944 through 1947. The average of the estimated leadtimes of the latter group is approximately 7 years and that of the earlier group approximately 10-1/2 years, a reduction of 3-1/2 years. It is likely, however, that this apparent reduction in leadtime is optimistic since estimates have generally been optimistic in the past.

For the eight operational systems it was determined (see Appendix C) that no more than 10 percent of the estimates were optimistic by more than 3.6 years. Hence, it appears likely that the average leadtimes for the post-1950 systems will be less than the average leadtime for the pre-1950 systems. However, the following paragraph discusses an important reservation on this apparent leadtime reduction.

Figure 7 portrays leadtimes for seven strategic bombers plotted in the same manner as the data shown in Figure 6. This figure was included to show another family of weapon systems in which increased leadtimes have been required for the later developments. Some influences tend to reduce leadtime for later systems some tend to increase it; in the case of the strategic bombers, the factors tending to increase leadtime predominated. Since the balance between the factors tending to increase and those tending to decrease missile system leadtimes are unknown within the context of this study, it should not be inferred that the apparent trend of missile system leadtime reduction will necessarily continue.



KEY:

1. PETREL
2. CORPORAL E
3. NIKE-AJAX
4. MATADOR
5. SNARK
6. RASCAL
7. REGULUS I
8. TRITON
9. TALOS (Ship)
10. TERRIER
11. SPARROW I
12. FALCON
13. LACROSSE
14. REDSTONE
15. SIDEWINDER
16. BOMARC
17. ATLAS
18. SPARROW III
19. HAWK
20. TARTAR
21. BULLPUP
22. NIKE-HERCULES
23. DART
24. REGULUS II
25. SERGEANT
26. TALOS (Land)
27. NIKE-ZEUS
28. JUPITER
29. THOR
30. POLARIS
31. TITAN

● ACTUAL LEADTIMES FOR OPERATIONAL SYSTEMS

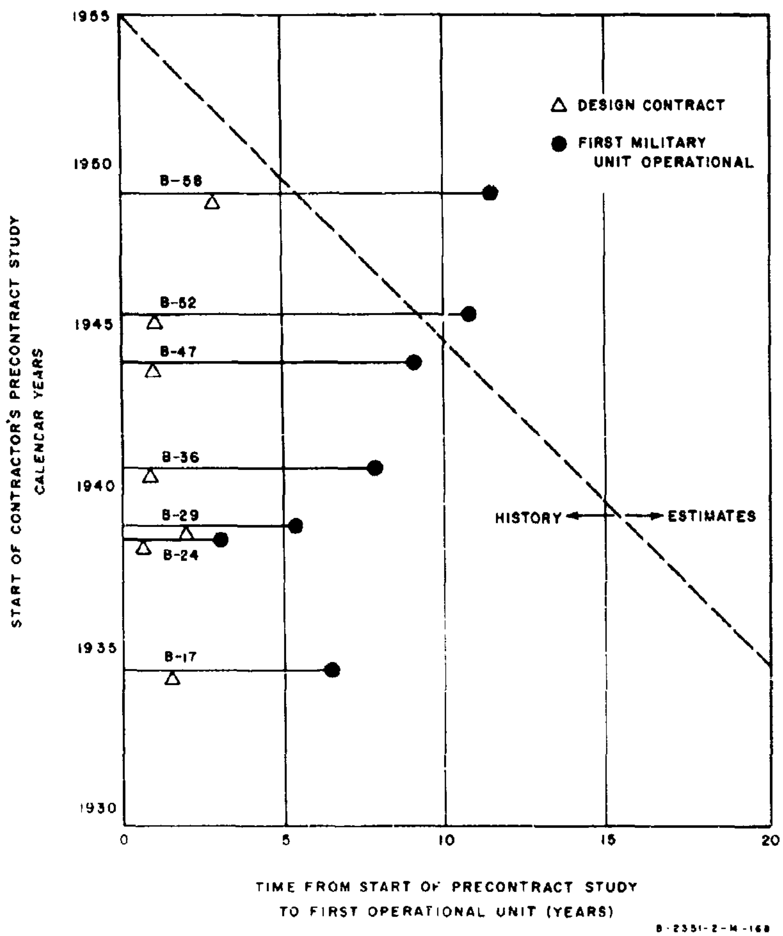
◐ ESTIMATED LEADTIMES FOR SYSTEMS NOT OPERATIONAL BY MID-1957.

NOTE: The nine operational guided missile systems lie to the left of the dashed line

SOURCE: Appendix Table A-2

FIG. 6

ACTUAL AND ESTIMATED LEADTIMES AS A FUNCTION OF DATE
OF PROJECT INITIATION FOR THIRTY-ONE GUIDED MISSILE SYSTEMS



Source. Set of charts, "Estimated Completion Dates." Hq. ARDC, Baltimore, Md.

FIG. 7

TIME FROM START OF PRECONTRACT STUDY
TO OPERATIONAL AVAILABILITY FOR STRATEGIC BOMBERS

Section VI

RELATIONSHIP OF TIME TO FIRST PRODUCTION CONTRACT TO TOTAL LEADTIME

Presumably, the signing of the first production contract for a missile system would indicate that the system design has been sufficiently proved to warrant translating it into production hardware, and that it should therefore be a good indicator of progress of a system's development.

Data relating the first production contract date to the project start and the operation availability dates are presented in this section to show how much similarity exists between weapon systems in this respect.

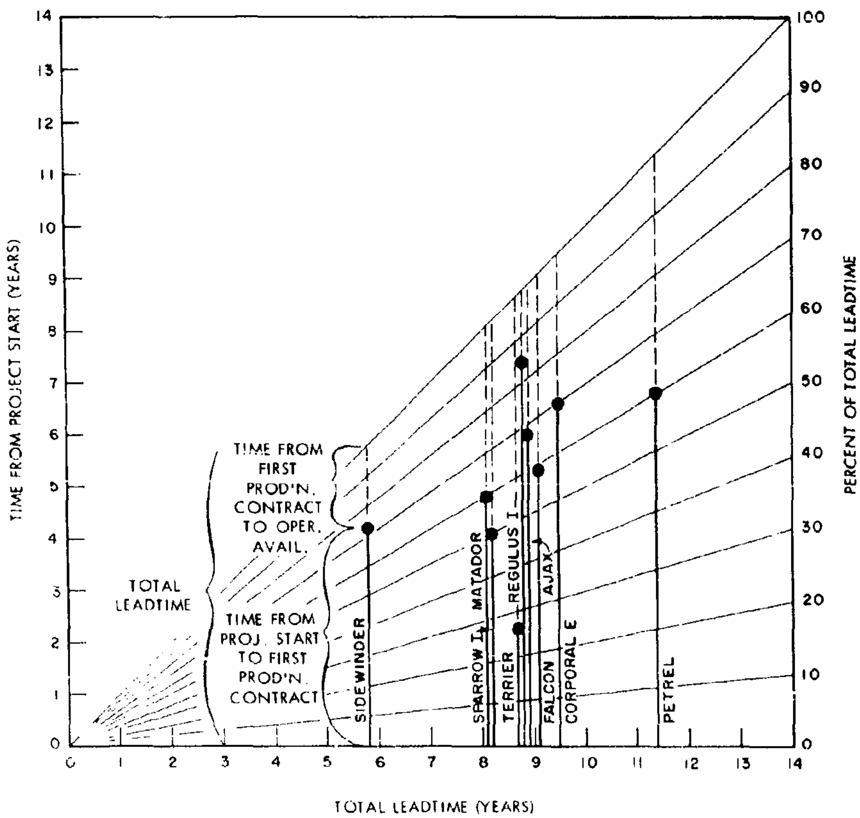
Two sets of data are plotted. In Figure 8 are shown data for nine operational missile systems. In Figure 9 are shown actual and estimated data for eleven of the nonoperational systems for which data are available.

In both figures a vertical line for each system represents the actual time duration from project start to first production contract. It is plotted on the horizontal scale according to the actual (Figure 8) or estimated (Figure 9) leadtime to operational availability in order to show the relationship between the length of time spent prior to the first production contract and the total leadtime to become operational.

Figure 8 shows the relationship for the nine operational systems. In five (55 percent) of these systems, 59 to 70 percent of the total operational leadtime was spent prior to the first production contract. The extremes for all nine systems range from 26 percent to 84 percent.

Expressed in terms of years after the first production contract, five of the systems (55 percent) took 2.8 to 4.2 years to reach operational status (extremes for all nine range from 1.4 to 6.5 years).

The state of increased military urgency during and after the Korean conflict quite possibly affects the pattern of Figure 8. Eight of these nine systems were initiated between 1944 and 1947. Of the eight, first production contracts for five systems were signed between the end of 1950 and mid-1951 during the Korean conflict. (See Appendix Table A-6.) This close grouping of first production contracts suggests that there may be a relationship between military or political "urgency" and the first production contract that is perhaps as important to the relationship between system readiness for production and the contract.



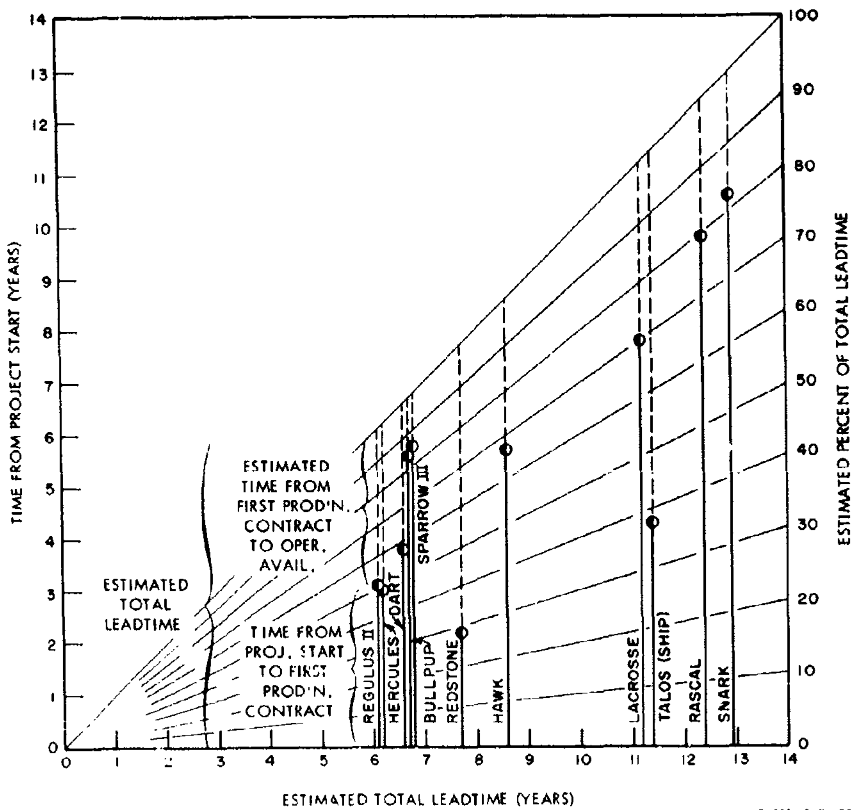
● FIRST PRODUCTION CONTRACT

NOTE Cut-off date of data: 30 June 1957

SOURCE Appendix Table A - 6

FIG. 8

TIME TO FIRST PRODUCTION CONTRACT VS TOTAL LEADTIME
FOR NINE OPERATIONAL GUIDED MISSILE SYSTEMS



FIRST PRODUCTION CONTRACT

NOTES: 1. Cut-off date of data, 30 June 1957.
2. First production contract points are plotted at the project leadtime estimate as of 30 June 1957.

SOURCE: Appendix Table A - 7

FIG. 9

TIME TO FIRST PRODUCTION CONTRACT VS ESTIMATED TOTAL LEADTIME FOR ELEVEN NONOPERATIONAL GUIDED MISSILE SYSTEMS

Figure 9, describing eleven nonoperational systems, shows that, as of mid-1957, there is wide variation of estimated time spent prior to the first production contract, from 29 percent to 84 percent of the time to the estimated first operational availability. There is less tendency for the estimates to fall into groups by percentage for the nonoperational than for the operational systems. Nine of the eleven systems (82 percent) were estimated, as of 30 June 1957, to require 3.4 years or less from first production contract to operational status (see Appendix Table A-7). Since the current estimates of total leadtime are probably optimistic, as discussed in Section IV, some points can be expected to move to the right with time (i.e., actual total leadtimes may be greater). The precise effect on the pattern as plotted cannot be forecast.

In general, it can be said that for seven of the nine operational systems about one-half to three-quarters (50 to 75 percent) of their total leadtime to operational status was expended prior to the first production contract and they required from 1.4 to 4.1 years from first production contract to operational status.

The eleven nonoperational systems show wider variation, and the pattern of variation will probably change as they become operational.

Section VII

ARMY MISSILES: TIME FOR RESEARCH, DEVELOPMENT, TEST, OPERATIONAL EVALUATION, OPERATIONAL AVAILABILITY

Figure 10 establishes, for each of eleven Army missile systems for which data were available, a base line (project start to operational availability) which is marked to show estimated and actual completion dates for the phases of research, development, test, and operational evaluation. The purpose of this figure is to determine the relationships between the estimated or actual completion dates for research, development, test, and operational evaluation in terms of the estimated or actual completion date for operational availability. The phases are those defined in the Department of the Army Annual Guided Missile Progress Reports to the Department of Defense:

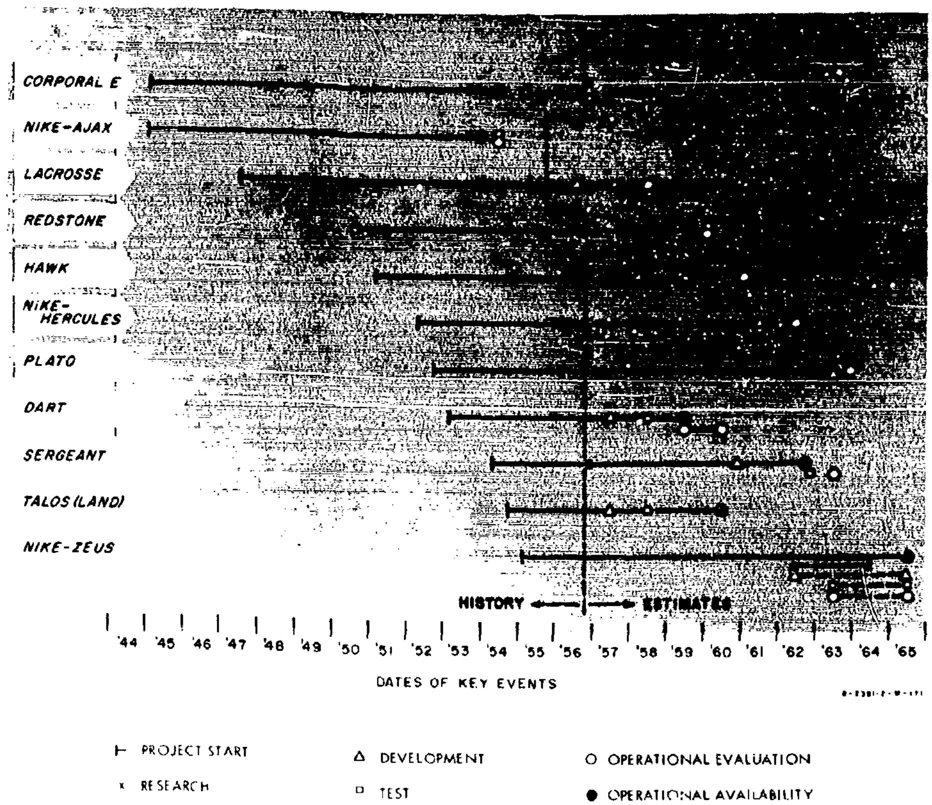
Research--theoretical analysis, exploration, without completely defined goals, directed toward the increase of knowledge and, with it, the power to control phenomena.

Development--the extension of the investigative findings and theories of a scientific or technical nature into practical application for experimental or demonstration purposes, including the construction and testing of experimental models or devices but excluding operational or service tests.

Test--the physical and performance measurement of a specifically developed item (material, equipment, system, or device) to determine the technical suitability of the item for use in the military services.

Operational Evaluation--the test of a specifically developed item (material, equipment, system, or device) under service or simulated service conditions in order to determine as accurately as possible its characteristics or performance and its utility in military operations.

Operational availability is defined as the date when the first unit is equipped to have capability for action against the enemy (i.e., the same date that is used in the earlier sections of this report).



SOURCE: Appendix Table A - 8.

FIG. 10

ACTUAL AND ESTIMATED COMPLETION DATES FOR PHASES OF ARMY GUIDED MISSILE SYSTEMS

The following observations are made from Figure 10:

1. Research was completed or estimated to be completed before operational availability in six out of nine systems (no dates available for DART and TALOS). Estimates range from 7-1/2 years before operational availability to 2-1/2 years after operational availability.

2. Development was completed or estimated to be completed before operational availability in seven out of ten systems (no date available for REDSTONE). Estimates range from 3 years before operational availability to 5-1/2 years after operational availability.

3. Testing was completed or estimated to be completed before operational availability in five out of ten systems (no data available for PLATO). Estimates range from 2 years before operational availability to 3 years after operational availability.

4. Operational evaluation was completed or estimated to be completed before operational availability in two out of eight systems (no data available on CORPORAL, PLATO, and TALOS). Estimates range from 2 years before operational availability to 4 years after operational availability.

One would normally expect that research, development, and test for a specific system configuration would occur before that system becomes operational. The data do not reflect this relationship; the data do not identify the smaller variations of system configuration. Evidently the data refer in many cases to advanced configurations, as indicated by the numerous extensions of the estimated completion dates for R&D phases beyond the dates of operational availability: for example, research is completed up to 2-1 2 years, development, up to 5-1/2 years, and test, up to 3 years after operational availability.

The data show little reasonable pattern. It is concluded that the present reporting system for estimated completion dates in the Annual Guided Missile Progress Reports is inadequate to demonstrate the relationship of R&D functions to operational availability of the first unit. It appears that the definitions of research, development, test, and operational evaluation are not or cannot be related by the estimator to specific system configurations.

Section VIII

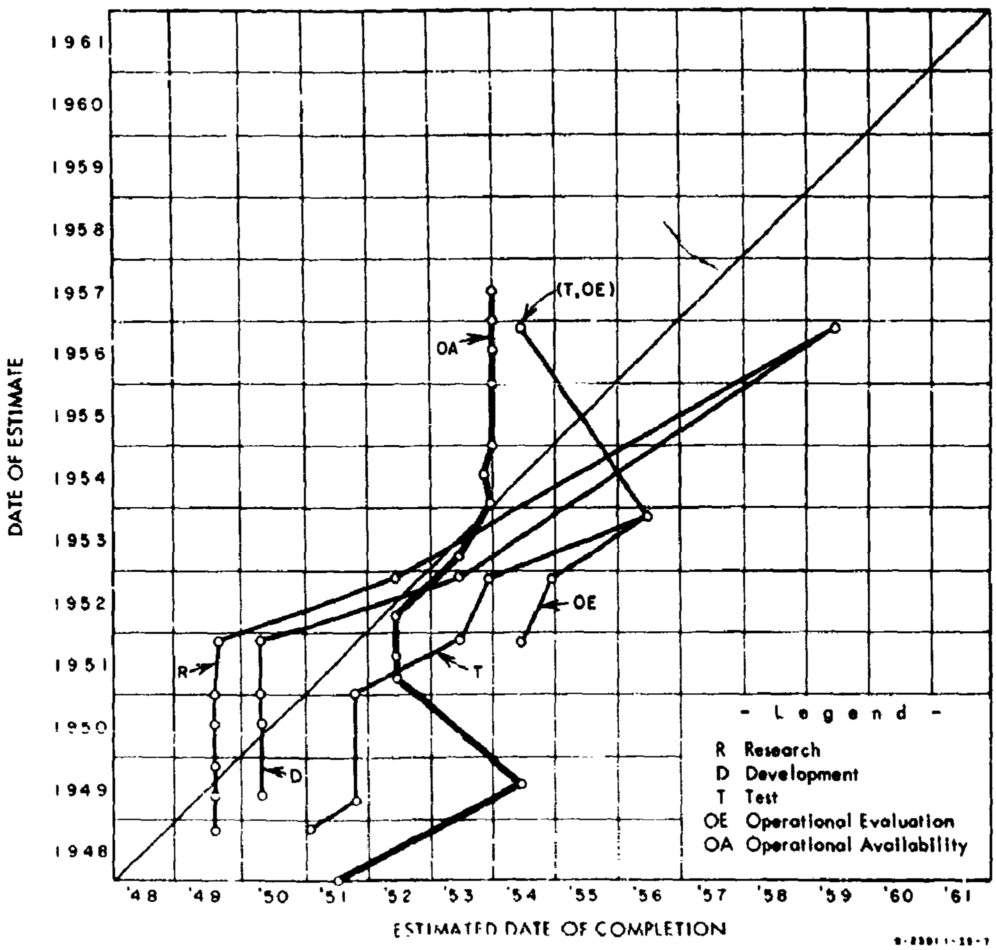
ERRORS IN ESTIMATING R&D PHASES FOR THE ARMY'S SAM FAMILY

The previous section demonstrated the lack of [illegible] relationships between operational availability and the latest estimated completion dates for research, development, test, and operational evaluation of the Army missile systems. In this section, five of the Army's surface-to-air missile systems (NIKE-AJAX, NIKE-HERCULES, HAWK, PLATO, and TALOS (land-based)) are selected to demonstrate the errors in estimating the completion dates of research, development, test, and operational evaluation.

Figures 11 to 15 are plots of several series of estimates of the occurrence of specified events in the five missile systems. The dates of the estimates are plotted on the vertical scale, and the estimated dates of completion of the specified events are plotted on the horizontal scale. Estimated dates for as many as five events are shown for each missile system: completion of research (R), development (D), test (T) operational evaluation (OE), and first operational availability (OA). These events, which are defined in the legend of each figure, are customarily used by the services in rendering the Annual Guided Missile Progress Report (in October of each year).

As shown in Figures 11 to 15, the slippage rates of the estimated completion dates for research, development, test, and operational evaluation are, in most cases, greater than the slippage rate of the [illegible] date for operational availability. The range of difference between [illegible] and latest estimated completion dates for research is 0.2-9.9 years; for development, 0-9.2 years; for test, 0-4 years; and for operational evaluation, 0-3 years. By contrast, the same range for operational availability is 0.5-2.5 years. The explanation of this greater variation [illegible] lies in the areas of (1) the apparent greater difficulty of ac[illegible]ly estimating research and development completion dates and (2) the [illegible] reporting of the relationship between R&D and specific system [illegible]tions. Note that the variations of errors become successively smaller as one uses events with easily determined dates such as test, [illegible] evaluation, and operational availability.

SECRET

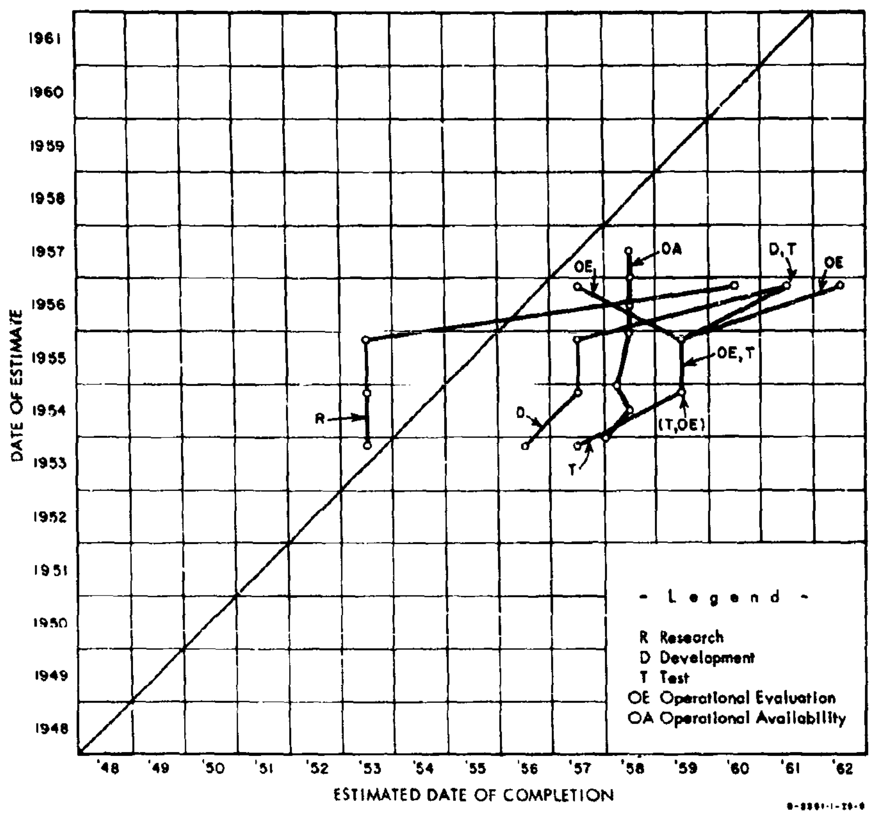


SOURCES: R, D, T, OE - Annual Guided Missile Progress Reports, Department of Army
OA - DOD Guided Missile Program Tables, D/A Estimates

FIG. 11

ESTIMATED COMPLETION DATES FOR PHASES
OF NIKE-AJAX MISSILE SYSTEMS

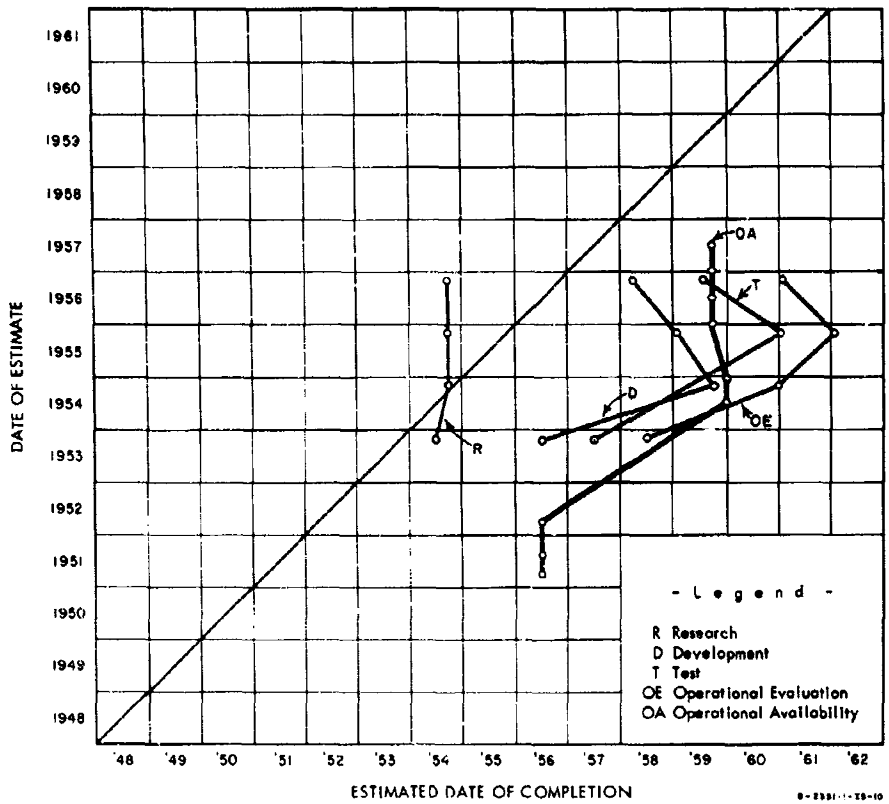
SECRET



SOURCES: R, D, T, OE - Annual Guided Missile Progress Reports, Department of Army
OA - DOD Guided Missile Program Tables, D/A Estimates

FIG. 12

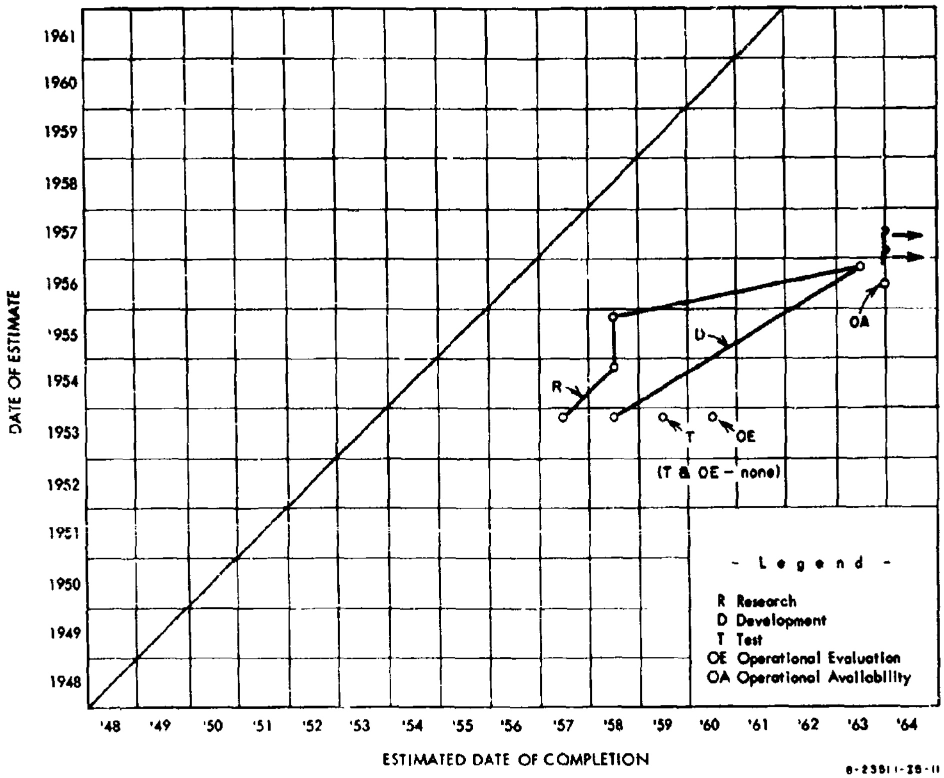
ESTIMATED COMPLETION DATES FOR PHASES OF NIKE-HERCULES MISSILE SYSTEM



SOURCES: R, D, T, OE - Annual Guided Missile Progress Reports, Department of Army
OA - DOD Guided Missile Program Tables, D/A Estimates

FIG. 13

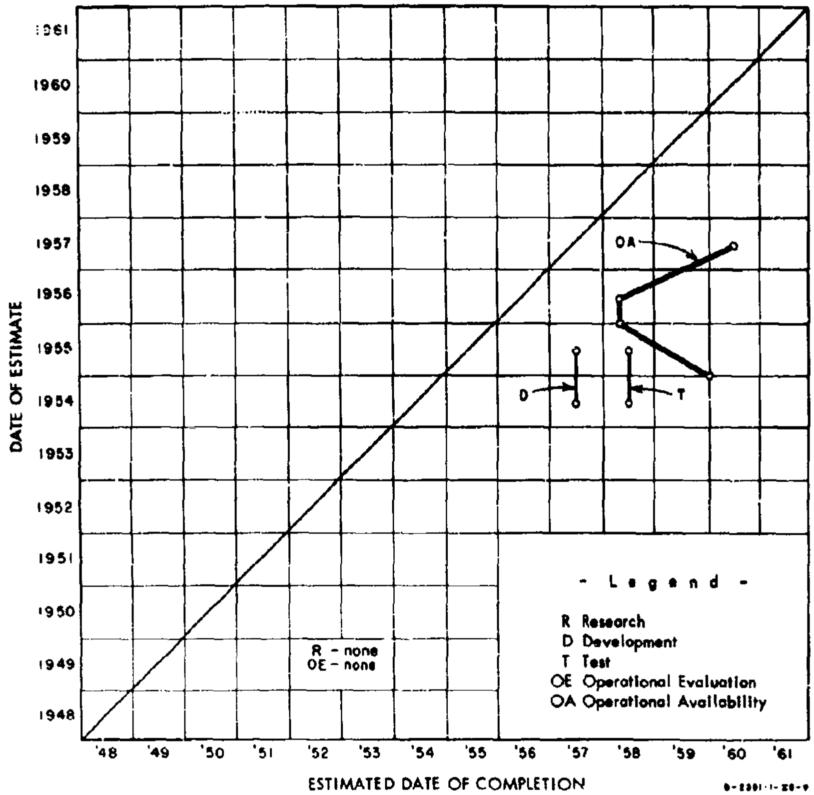
ESTIMATED COMPLETION DATES FOR PHASES
OF HAWK MISSILE SYSTEM



SOURCES: R, D, T, OE - Annual Guided Missile Progress Reports, Department of Army
OA - DOD Guided Missile Program Tables, D/A Estimates

FIG. 14

ESTIMATED COMPLETION DATES FOR PHASES
OF PLATO MISSILE SYSTEM



SOURCES: R, D, T, OE - Annual Guided Missile Progress Reports, Department of Army
OA - DOD Guided Missile Program Tables, D/A Estimates

FIG. 15

ESTIMATED COMPLETION DATES FOR PHASES OF TALOS (LAND-BASED) MISSILE SYSTEM

Section IX

USE OF LEADTIME AND ESTIMATING ERROR DATA

Data have been presented in the preceding sections with only occasional reference to the possible cause-and-effect relationships which suggest why leadtimes vary from system to system or why estimates prove to be inaccurate. If the data are to be used at all, however, some understanding of these relationships is necessary for interpreting the meaning of the data to guide their proper use. Detailed examination of these causal relationships is beyond the scope of this research; however, during the course of the research, it was necessary to establish the general framework of factors affecting leadtime and the factors affecting the accuracy of estimates. The relationships and their effect on the applications of the data are discussed below.

Leadtime Data Characteristics

Leadtimes for complex weapon systems can be expected to show some similarity. Some minimum leadtime is necessary under the most favorable conditions to integrate components into systems and test them, tool up and produce equipment, train personnel, install launching equipment, and deploy tactical units. Some maximum leadtime is also to be expected. In a time of rapid change of military technology, weapon systems which require very long leadtimes are likely to become obsolescent and to be cancelled prior to becoming operational.

The data show the wide variation between these extremes that can be expected. Logically, leadtimes are affected by at least the following factors: advance required in the state of the art, technical complexity, organization complexity, relative state of urgency for the system, and the national state of urgency. These factors are not accurately known for the future with any assurance, nor is their effect on leadtimes known quantitatively.

Use of Leadtime Data

It is evident from the discussion above that the historical leadtime data must be used in conjunction with the best available knowledge of the qualitative factors affecting leadtime for specific weapon systems. Used in this way, the historical leadtime data can be of advantage in two areas:

1. Estimates can be compared with the historical data. Marked deviations of the estimates from historical leadtimes required by systems which were similar with respect to factors affecting leadtime can call attention to the need for more careful examination of the estimates.

2. Where long-range plans require assumptions about system leadtimes, the data can be useful if the results of the planning are not sensitive to the accuracy of the leadtime assumed for any one system.

Estimating Error

"Estimating error" is used in this report in a specialized sense to mean the difference between estimated and actual dates regardless of cause and independent of any connotation of blame. In the sense of this definition, a wide range of errors can be expected because of the difficulty of defining "realistic" conditions and assumptions and the difficulty of estimating for very complex missile systems what could be done in a stated time, even if all conditions and assumptions were satisfied. The data show that errors have a pronounced tendency to be on the optimistic side of the possible range of error. Several reasons, which are illustrative rather than comprehensive, can be stated for this tendency:

1. Detailed estimates originate with contractors and military project managements. These organizations are oriented to their systems and can be expected to be biased in their favor.

2. The military's desire for shorter leadtimes encourages optimistic estimates.

3. Estimates made early in the development of a weapon system originate with R&D organizations which tend to underrate the difficulties of hardware production, personnel training, and system deployment.

4. The military's decision-makers frequently require estimates based on optimistic priority assumptions by each weapon system. It is the decision-makers' prerogative to effect, system by system, high or low priority programs. A net reduction in the priorities assumed results in optimistic error.

5. Many events or conditions which increase leadtime but which have a low probability of occurring in any one system development can not meaningfully be taken into account by estimators.

On the basis of both the apparent tendency shown by the data on non-operational systems and the discussion above, it appears that estimates will continue to be optimistic.

Use of Error Data

It is important to consider the consequences of reducing or eliminating the average optimistic bias from a set of estimates. Since the degree of optimistic error varies widely from system to system, compensation for the average optimistic error will change the estimates from nearly all optimistic to approximately half optimistic and half pessimistic. For some purposes the penalty attached to a pessimistic estimate may be greater than that attached to an estimate which is optimistic by the same amount of time. For example, failure to provide funding for long leadtime elements, on the basis of a pessimistic estimate, may cause delay in a system's development that may be more serious than tying up obligated funds (provided on the basis of an optimistic estimate) which will not be expended as soon as scheduled. As a further example, if compensation for optimistic error is made to estimates for some systems, and if these estimates are compared with uncompensated estimates for other systems, faulty conclusions and decisions can result.

If the consequences noted above are taken into consideration, the estimating error data can be used to advantage in evaluating current estimates for purposes of program planning and control. The data indicate a pronounced tendency for estimates to be optimistic. The evaluator can be conditioned by these data to be more critical of the realism of assumptions on which estimates are based.

The magnitude and range of optimistic errors in the data suggest a need for further research, first on the causes of error in estimating, and subsequently, on the possibilities of improved program planning based on knowledge of the causes.

Appendix A

STATISTICAL TABLES

Table A-1

ACTUAL AND ESTIMATED LEADTIMES FOR ARMY, NAVY, AND AIR FORCE MISSILE SYSTEMS
As of 30 June 1957

Missile System	Project Start Date	Derivation of Operational Leadtimes			
		9 Operational Systems		22 Nonoperational Systems	
		Operational Availability Date[1]	Leadtime (years) (2)-(1)	Latest Est. of Opnl. Avail. Date as of 6/57[1]	Est. Leadtime (years)[4] (4)-(1)
	(1)	(2)	(3)	(4)	(5)
SAM					
NIKE-AJAX	2/46[1,2]	1/54	8.9		
NIKE-HERCULES	4/52[2]			7/58	6.2
NIKE-ZEUS	2/55[2]			1965	10.3
TERRIER	11/46[1]	7/55	8.7		
TALOS (Ship) 6b	11/46[1]			4/58	11.4
TALOS (Land)	9/54[3]			1960	5.8
BOMARC (IM-99A)	1/51[1,2]			9/59	8.7
TARTAR	6/51[2]			3/60	8.8
HAWK	3/51[1,2]			10/59	8.6
AAM					
SPARROW I	12/46[1,2]	4/55	8.3		
SPARROW III	1/51[1]			11/57	6.8
FALCON (GAR-1)	3/47[1,2]	4/56	9.1		
SIDEWINDER	9/50[1]	7/56	5.8		
ASM					
RASCAL	5/46[1,2]			9/58	12.3
BULLPUP	4/52[2]			12/58	6.7
AUM					
PETREL	8/44[1,2]	1/56	11.4		
SSM					
MATADOR (TM-61A)	2/46[1,2]	3/54	8.1		
REGULUS I	6/48[1,2]	4/55	6.8		
CORPORAL E	12/44[1,2]	6/54	9.5		
REDSTONE	7/50[2]			3/58	7.7
LACROSSE	7/47[1,2]			10/58	11.2
DART	12/52[2]			7/59	6.6
SERGEANT	4/54[2]			9/62	8.4
JUPITER	6/55[2]			7/59	4.1
THOR	6/55[2]			7/59	4.1
REGULUS II	6/53[1,2]			7/59	6.1
POLARIS	11/55[2]			1963	7.6
TRITON	9/46[1,2]			1965	18.8
SNARK	2/46[1,2]			1/59	12.9
ATLAS	1/51[2]			3/59	8.2
TITAN	12/55[2]			3/61	5.2

1 Source: Office of Assistant Secretary of Defense, R&E.
2 Source: Annual GM Progress Reports, Depts. of Army, Navy, AF.
3 Source: ORO-R-17
4 Where only the year is given in the estimate, leadtimes are calculated assuming the month to be June

Table A-2

ACTUAL AND ESTIMATED COMPLETION DATES FOR OPERATIONAL AVAILABILITY OF NINE OPERATIONAL GUIDED MISSILE SYSTEMS

System	Service	Date of Project Start	Estimated Completion Date by Date of Estimate																
			Apr. 47	Nov. 47	May 48	Jan. 49	June 49	Jan. 50	June 50	Mar. 51	July 51	Mar. 52	Mar. 53	June 54	Dec. 54	June 55	Dec. 55	June 56	Dec. 56
TERRIER	N	Nov. 46	53	53	—	52	53	52	—	53	53	53	54	55	56	56	July 55	—	—
NIKE-AJAX	A	Feb. 45	—	51	—	—	54	—	—	52	52	52	53	Jan. 54	—	—	Jan. 54	—	—
PETREL	N	Aug. 44	51	48	52	51	52	53	—	54	54	54	54	55	55	55	55	56	Jan. 56
FALCON	AF	Mar. 47	—	—	52	54	54	54	—	54	54	55	55	56	56	56	56	Apr. 56	—
SPARROW I	N	Dec. 46	52	53	54	—	55	53	—	53	53	54	54	55	55	55	Apr. 55	—	—
SIDEWINDER	N	Sept. 50	—	—	—	—	—	—	—	—	—	54	55	56	56	56	56	56	July 56
REGULUS I	N	June 46	53	53	54	54	54	56	—	55	55	55	54	54	55	Apr. 55	—	—	—
MATADOR	AF	Feb. 46	50	52	53	51	52	52	—	52	52	53	—	Jan. 54	Jan. 54	—	Mar. 54	—	—
CORPORAL E	A	Dec. 44	—	50	—	—	—	—	53	—	—	—	—	—	—	—	—	June 54	—

Source: Office of the Assistant Secretary of Defense for Research and Engineering.

SECRET

Table A-3

OPTIMISTIC ERRORS IN ESTIMATING OPERATIONAL AVAILABILI'Y
OF EIGHT GUIDED MISSILE SYSTEMS

Dates of Estimate	TERRIER ED	TERRIER ATG (yr)	TERRIER ETG (yr)	TERRIER Er (yr)	NIKE-AJAX ED	NIKE-AJAX ATG (yr)	NIKE-AJAX ETG (yr)	NIKE-AJAX Er (yr)	PETREL ED	PETREL ATG (yr)	PETREL ETG (yr)	PETREL Er (yr)	FALCON ED	FALCON ATG (yr)	FALCON ETG (yr)	FALCON Er (yr)	SPARROW I ED	SPARROW I ATG (yr)	SPARROW I ETG (yr)
3-47	6/53	8.3	6.2	2.1					6/51	8.8	4.2	4.6					[illegible]/52	8.1	5.[illegible]
11-47	6/53	7.7	5.6	2.1	6/51	6.2	3.6	2.6	6/48	8.2	0.6	7.6					6/53	[illegible]	5.0
5-48									6/52	7.7	4.1	3.6	6/52	7.9	[illegible].1	[illegible]	6/54	6.9	6.[illegible]
1-49	6/52	6.5	3.1	3.1					6/51	7.0	2.4	4.6	6/54	7.5	[illegible]	[illegible]			
6-49	6/53	6.1	4.0	2.1	6/54	4.6	5.0	-0.4	6/52	6.6	3.0	3.[illegible]	6/54	6.4	5.[illegible]	1.[illegible]	6/55	5.[illegible]	6.[illegible]
1-50	6/52	5.5	2.4	3.1					6/53	6.0	3.4	2.[illegible]	6/54	[illegible]	1.5	1.8	6/57	5.[illegible]	[illegible].5
3-51	6/53	4.3	2.2	2.1	6/52	2.8	1.2	1.6	6/54	4.8	3.2	1.[illegible]	6/54	[illegible]	[illegible]	1.8	6/53	[illegible].1	2.[illegible]
7-51	6/53	[illegible].0	1.9	2.1	6/52	2.5	0.9	1.6	6/54	4.5	2.9	1.6	6/54	1.8	[illegible]	1.8	6/[illegible]	3.6	[illegible]
3-52	6/53	3.3	1.2	2.1	6/52	1.8	0.2	1.6	6/54	3.8	2.2	[illegible].6	6/55	4.[illegible]	3.[illegible]	0.8	6/54	[illegible].1	[illegible]
3-53	6/54	2.3	1.2	1.1	6/53	0.8	[illegible]2	0.6	6/54	2.8	1.2	[illegible].6	6/55	[illegible]	[illegible]	0.8	3/54	2.1	1.[illegible]
5-54	6/55	1.1	1.0	0.1					6/55	1.6	1.0	[illegible].6	6/56	1.[illegible]	[illegible]	-0.2	[illegible]/55	0.8	1.[illegible]
12-54	6/56	0.6	1.5	-0.9					6/55	1.1	0.5	[illegible].6	6/56	1.[illegible]	1.3	-0.2	[illegible]/55	[illegible]	0.[illegible]
6-55	6/56	0.1	1.0	-0.9					6/55	0.6	0.0	[illegible].6	6/56	0.8	1.0	-0.2			
12-55									6/55	0.1	-0.5	[illegible].6	6/56	0.3	0.5	-0.2			
6-56																			
12-56																			
4-57																			
Actual Date of Operational Availability	7/55				1/54				1/56				[illegible]				4/[illegible]		

RECAPITULATION OF [illegible]

ATG by Half-Year Intervals	TERRIER	NIKE-AJAX	PETREL	FALCON	SPARROW I	SIDEWINDER	REGULUS I	MATADOR	Total	Average
9.0			1.2						1.2	1.2
8.5	6.2								6.2	6.2
8.0			0.6	1.1	5.3		6.[illegible]		16.3	4.1
7.5	5.6		1.1	5.5	5.6		5.6		26.1	5.3
7.0			2.[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
6.5	3.1		[illegible]	1.5			5.5	1.6	21.0	1.2
6.0	4.0	3.6	[illegible]		6.0		5.0	[illegible]	27.1	1.5
5.5	2.4				3.5		6.5		[illegible]	1.1
5.0			[illegible]	[illegible], [illegible]				2.1, [illegible]	14.0	[illegible]
4.5	2.2	[illegible]	2.0			[illegible].2			[illegible]	[illegible]
4.0	1.9		[illegible]	[illegible]	[illegible], [illegible]		1.[illegible], 1.[illegible]	[illegible]	[illegible]	2.8
3.5	1.7					[illegible]			[illegible]	1.7
3.0		1.[illegible]	1.[illegible]	[illegible]	[illegible]		[illegible]	1.[illegible]	11.[illegible]	[illegible]
2.5	1.[illegible]	[illegible]						[illegible]	[illegible]	[illegible]
2.0		[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1.5			1.[illegible]	1.5		[illegible]			1.[illegible]	1.[illegible]
1.0	1.[illegible]	[illegible]	[illegible]	1.[illegible]	1.[illegible]	[illegible]	[illegible]		1.[illegible]	[illegible]
[illegible]	1.[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
[illegible]	1.[illegible]		[illegible]			[illegible]				[illegible]

ETG by Half-Year Intervals	TERRIER	NIKE-AJAX
7.0		
6.5		
6.0	2.1	
5.5	2.1	
5.0		[illegible]
4.5		
4.0	2.1	
3.5	3.1	[illegible]
3.0		
2.5	3.1	
2.0	2.1, 2.2	
1.5	[illegible]	
1.0	[illegible], 2.1, [illegible]	1.6 1.6
[illegible]		
[illegible]		[illegible] [illegible]
[illegible]		

Legend:

ED Estimated Date of Operational Availability [illegible] future [illegible]
ATG Actual Time-to-Go, [illegible] operational [illegible]
ETG Estimated Time-to-Go, [illegible]
Er [illegible]

[illegible]

SECRET

Table A-3

N ESTIMATING OPERAT[illegible] AVAILABILITY
HT GUIDED MISSILE SY[illegible]

NIKE-AJAX ATG (yr)	NIKE-AJAX [illegible] (yr)	NIKE-AJAX Er (yr)	PETREL ED	PETREL ATG (yr)	PETREL ETG (yr)	PETREL Er (yr)	FALCON ED	FALCON ATG (yr)	FALCON ETG (yr)	FALCON Er (yr)
			6/[illegible]	8.8	4.2	1.6				
[illegible]	3.5	2.6	6/48	8.2	[illegible]	7.6				
			6/52	[illegible]	1.1	[illegible]	6/[illegible]	7.9	4.1	3.8
			6/51	7.0	[illegible]	1.6	6/51	7.3	5.5	1.8
[illegible]	[illegible]	[illegible]	6/5[illegible]	6.6	[illegible]	1.6	6/51	6.8	5.0	1.8
[illegible]			6/5[illegible]	[illegible]	[illegible]	2.6	6/51	[illegible]	1.5	1.8
[illegible]	[illegible]	1.6	6/5[illegible]	1.8	[illegible]	1.6	6/51	5.1	3.3	1.8
1.8	[illegible]	1.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.0	1.8
0.8	[illegible]	1.6	6/[illegible]	[illegible]	[illegible]	[illegible]	6/55	[illegible]	3.4	0.8
		0.6	6/[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	2.3	0.8
			[illegible]	1.6	[illegible]	[illegible]	[illegible]	[illegible]	2.0	[illegible]
			[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	1.5	-0.2
			[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	1.0	-0.2
			[illegible]	[illegible]	[illegible]	[illegible]			0.5	-0.2
							[illegible]			

SPARROW I ED	SPARROW I ATG (yr)	SPARROW I ETG (yr)	SPARROW I Er (yr)	SIDEWINDER ED	SIDEWINDER ATG (yr)	SIDEWINDER ETG (yr)	SIDEWINDER Er (yr)	REGULUS I ED	REGULUS I ATG (yr)	REGULUS I ETG (yr)	REGULUS I Er (yr)	MATADOR ED	MATADOR ATG (yr)	MATADOR ETG (yr)	MATADOR Er (yr)
6/52	8.1	5.3	2.8					6/53	8.1	6.3	1.8	6/50	7.0	3.2	3.8
6/53	7.4	5.6	1.8					6/53	7.1	5.6	1.8	6/52	6.3	4.6	1.7
6/54	6.9	6.1	0.8					6/54	6.9	6.1	0.8	6/53	5.8	5.1	0.7
								6/54	6.3	5.5	0.8	6/51	5.2	3.4	2.8
6/55	5.8	6.0	-0.2					6/54	5.8	5.0	0.8	6/52	4.8	3.0	1.8
6/53	5.3	3.5	1.8					6/56	5.3	6.5	-1.2	6/52	4.2	2.4	1.8
6/53	1.1	2.3	1.8					6/55	4.1	4.3	-0.2	6/52	3.0	1.2	1.8
6/53	3.8	2.0	1.8					6/55	3.8	4.0	-0.2	6/52	2.7	0.9	1.8
[illegible]	[illegible]	2.3	0.8	6/54	4.3	2.2	2.1	6/55	3.1	3.3	-0.2	6/53	2.0	1.2	0.8
6/54	[illegible]	1.3	0.8	6/55	3.3	2.2	1.1	6/54	2.1	1.3	0.8				
[illegible]/55	0.8	1.0	-0.2	6/56	2.1	2.0	0.1	6/54	0.8	0.	0.8				
6/[illegible]	0.3	0.5	-0.2	6/56	1.6	1.5	0.1	6/55	0.3	0.5	-0.2				
				6/56	1.1	1.0	0.1								
				6/56	0.6	0.5	0.1								
				6/56	0.1	0.	0.1								
1[illegible]55				7/56				4/55				3/54			

[illegible]TABULATION OF DATA

Optimistic Errors of Estimate (Er) (years): TERRIER	NIKE-AJAX	PETREL	FALCON	SPARROW I	SIDEWINDER	REGULUS I	MATADOR	Total	Average
						1.8, -1.2		0.6	0.3
[illegible]				0.8, -0.2		0.8		3.5	0.9
[illegible]			1.8	2.8, 1.8		1.8, 0.8		11.1	1.8
	[illegible]		[illegible]			0.8	0.7	2.9	0.7
			1.8			-0.2	1.7	3.3	1.1
[illegible]		1.6, 3.6	3.8			-0.2		13.9	2.8
[illegible]	[illegible]	2.6	1.8, 0.8	1.8		[illegible]		12.5	1.8
		[illegible], 1.6, [illegible]	1.8				3.8, 1.8	14.2	2.4
3.1		4.6	0.8	1.8, 0.8			2.8, 1.8	15.7	2.2
[illegible], 2.1		1.6	-0.2	1.8	2.1, 1.1, 0.1			10.7	1.3
[illegible]			[illegible]	0.8	0.1	0.8		0.6	0.1
[illegible]	1.6	1.6, [illegible]	[illegible]	-0.2	0.1		1.8, 1.8, 0.8	11.9	0.8
		[illegible]	[illegible]	[illegible]	0.1	-0.2		7.7	1.3
	[illegible]				0.1	0.8		3.7	0.7
								0.6	0.6

2

SECRET

Table A-4

ESTIMATED COMPLETION DATES FOR OPERATIONAL AVAILABILITY OF THIRTEEN GUIDED MISSILE SYSTEMS NOT OPERATIONAL BY 30 JUNE 1957

System	Date of Project Start	Estimated Completion Date by Date of Estimate																	
		Apr. 47	Nov. 47	May 48	Jan. 49	June 49	Jan. 50	Mar. 51	July 51	Mar. 52	Mar. 53	June 54	Dec. 54	June 55	Dec. 55	June 56	Dec. 56	Apr. 57	June 57
SNARK	Feb. 46	54	54	53	53	54	54	54	54	55	56	58	—	58	58	59	59	Jan. 59	Jan. 59
RASCAL	May 46	52	54	53	54	54	54	54	54	55	54	56	57	57	57	57	58	Sept. 58	Sept. 58
TRITON	Sept. 46	--	53	53	53	59	59	59	59	59	-	--	-	--	65	65	65	65	65
TALOS (Ship)	Nov. 46	53	53	51	51	54	54	54	54	54	58	58	58	58	58	58	58	Apr. 58	Apr. 58
LACROSSE	July 47	--	—	--	53	55	--	54	54	55	--	58	58	--	59	58	59	Oct. 58	Oct. 58
REDSTONE	July 50	—	--	—	--	—	-	--	—	55	56	58	58	58	58	—	58	Apr. 58	Mar. 58
BOMARC	Jan. 51	--	--	--	--	--	--	54	54	55	57	58	60	60	59	59	59	Sept. 59	Sept. 59
SPARROW III	Jan. 51	-	--	--	--	--	--	—	54	53	--	56	56	57	57	57	57	Nov. 57	Nov. 57
HAWK	Mar. 51	--	-	--	--	—	--	56	56	56	--	60	60	60	59	59	59	Oct. 59	Oct. 59
BULLPUP	Apr. 52	--	--	--	-	--	--	--	--	—	--	57	57	58	58	58	Dec. 58	—	Dec. 58
HERCULES	Apr. 52	--	-	--	--	--	--	--	--	--	--	July 58	Mar. 58	--	July 58	July 58	July 58	--	July 58
DART	Dec. 52	--	-	--	--	--	--	--	--	--	--	58	59	59	59	59	59	July 59	July 59
SERGEANT	Apr. 54	--	--	--	-	--	--	--	--	--	--	--	July 61	--	July 62	Dec. 62	62	--	Sept. 62

Source: Office of the Assistant Secretary of Defense for Research and Engineering.

SECRET

Table A-5

ACTUAL AND ESTIMATED LEADTIMES AS A FUNCTION OF DATE OF PROJECT INITIATION FOR THIRTY-ONE GUIDED MISSILE SYSTEMS

System	Project Start Date	Leadtime (years)	
		Actual	Estimated
PETREL	8/44	11.4	
CORPORAL E	12/44	9.5	
NIKE-AJAX	2/45	8.9	
MATADOR	2/46	8.1	
SNARK	2/46		12.9
RASCAL	5/46		12.3
REGULUS I	6/46	8.8	
TRITON	9/46		18.8
TALOS (Ship)	11/46		11.4
TERRIER	11/46	8.7	
SPARROW I	12/46	8.3	
FALCON	3/47	9.1	
LACROSSE	7/47		11.2
REDSTONE	7/50		7.7
SIDEWINDER	9/50	5.8	
BOMARC	1/51		8.7
ATLAS	1/51		8.2
SPARROW III	1/51		6.8
HAWK	3/51		8.6
TARTAR	6/51		8.8
BULLPUP	4/52		6.7
NIKE-HERCULES	4/52		6.2
DART	12/52		6.6
REGULUS II	6/53		6.1
SERGEANT	4/54		8.4
TALOS (Land)	9/54		5.8
NIKE-ZEUS	2/55		10.3
JUPITER	6/55		4.1
THOR	6/55		4.1
POLARIS	11/55		7.6
TITAN	12/55		5.2

Source: Table A-1.

SECRET

Table A-6

TIME TO FIRST PRODUCTION CONTRACT VS TOTAL LEADTIME
FOR NINE OPERATIONAL GUIDED MISSILE SYSTEMS
As of 30 June 1957

Missile System	Project Start Date 1/	Date of First Production Contract 2/	Time from Project Start to First Production Contract (years)	Time from First Production Contract to Operational Availability (years)	Total Leadtime 1/ (years)	Time to First Production Contract as a Percent of Total Leadtime
SIDEWINDER	9/50	11/54	4.2	1.6	5.8	72
SPARROW I	12/46	1/51	4.1	4.2	8.3	49
MATADOR	2/46	12/50	4.8	3.3	8.1	59
TERRIER	11/46	2/49	2.2	6.5	8.7	25
REGULUS I	6/46	11/53	7.4	1.4	8.8	84
NIKE-AJAX	2/45	2/51	6.0	2.9	8.9	67
FALCON	3/47	7/52	5.3	3.8	9.1	58
CORPORAL E	12/44	7/51	6.6	2.9	9.5	69
PETREL	8/44	6/51	6.8	4.6	11.4	60

1/ Source: Table A-1.
2/ Source: Department of Defense, March 1958.

Table A-7

TIME TO FIRST PRODUCTION CONTRACT VS ESTIMATED TOTAL LEADTIME
FOR ELEVEN NONOPERATIONAL GUIDED MISSILE SYSTEMS
As of 30 June 1957

Missile System	Project Start Date 1/	Date of First Production Contract 2/	Time from Project Start to First Production Contract (years)	Time from First Production Contract to Estimated Date of Operational Availability (years)	Estimated Total Leadtime 1/ (years)	Time to First Production Contract as a Percent of Estimated Total Leadtime
REGULUS II	6/53	7/56	3.1	3.0	6.1	51
NIKE-HERCULES	4/52	4/55	3.0	3.2	6.2	48
DART	12/52	9/56	3.8	2.8	6.6	58
SPARROW III	1/51	10/56	5.8	1.0	6.8	85
BULLPUP	4/52	11/57	5.6	1.1	6.7	84
REDSTONE	7/50	10/52	2.2	5.5	7.7	29
HAWK	3/51	11/56	5.7	2.9	8.6	66
LACROSSE	7/47	5/55	7.8	3.4	11.2	70
TALOS (Ship)	11/46	3/51	4.3	7.1	11.4	38
RASCAL	5/46	2/56	9.8	2.5	12.3	80
SNARK	2/46	9/56	10.6	2.3	12.9	82

1/ Source: Table A-1.
2/ Source: Department of Defense, March 1958.

Table A-8

ACTUAL AND ESTIMATED COMPLETION DATES FOR
PHASES OF ARMY GUIDED MISSILE SYSTEMS

Missile System	Project Start Date	Date of Report	Actual and Estimated Completion Dates[1]				
			Research (R)	Development (D)	Testing (T)	Operational Evaluation (OE)	Operational Availability (OA)
CORPORAL E	12/44	10/56	12/5[illegible]	12/56	12/56	continuing	6/54
NIKE-AJAX	2/45	10/55	6/59[2]	6/59[2]	6/54[2]	6/54[2]	1/54
LACROSSE	7/47	10/55	1/54	7/56	7/57	7/58	9/58
REDSTONE	7/50	10/56	6/51 continuing	continuing	2/60	2/60	9/58
HAWK	3/51	10/56	9/54	3/58	7/59	1/61	9/59
NIKE-HERCULES	4/52	10/56	6/60[2]	6/61[2]	6/61[2]	6/62[2]	6/58
PLATO	9/52	10/56	6/63	6/63	--	--	12/63
DART	12/52	10/56	--	6/57[2]	6/58[2]	6/59[2] to 6/60[2]	6/59
SERGEANT	4/54	10/56	12/56	12/60	12/62	6/63[2]	9/62
TALOS (Land)	9/54	10/55	--	6/57[2]	6/58[2]	--	6/60[2]
NIKE-ZEUS	2/55	10/56	6/62[2] 6/64[2]	6/62[2] 6/65[2]	6/63[2] 6/65[2]	6/63[2] 6/65[2]	6/65[2]

1/ Historical dates or times are underlined; estimated dates or times are not underlined.
2/ Dates where only the year was given are assumed to be midyear.

Source: Annual Guided Missile Progress Reports, Department of the Army. Dates of reports are indicated in "Date of Report" column.

Table A-9

SLIPPAGE OF ESTIMATE FOR COMPLETION OF
SPECIFIED PHASES OF FIVE ARMY GUIDED MISSILE SYSTEMS

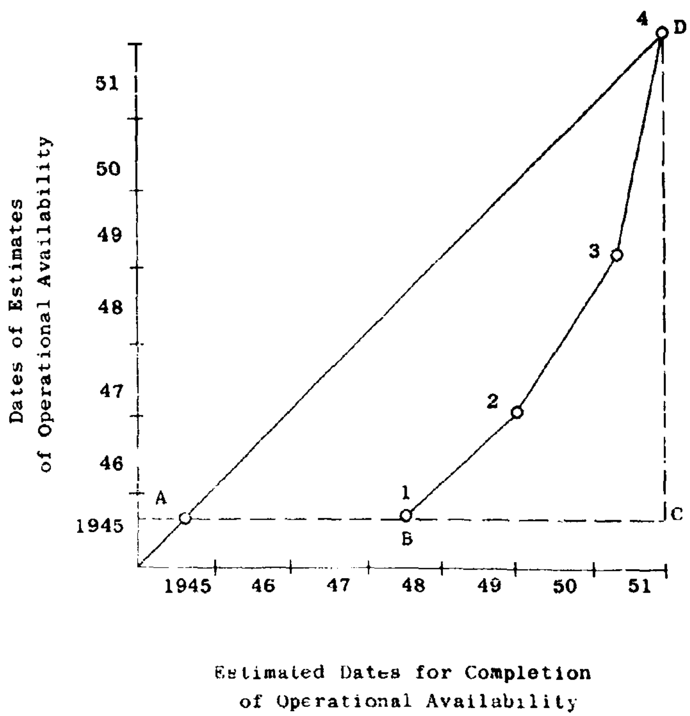
Missile System	(1) Phase[1/]	(2) Data Range From	(2) Data Range To	(3) Project Start	(4) First Estimated Completion Date	(5) Last Estimated Completion Date	(6) Slippage of Estimate (5)-(4) (years)	(7) Slippage Rate (6)÷(2) (yr/yr)
NIKE AJAX	R	10/48	10/56	2/45	7/49	6/50	9.9	1.2
	D	10/48	10/56		4/50	6/59	9.2	1.1
	T	10/48	10/56		1/51	6/54	3.4	0.4
	OE	10/51	10/56		6/54	6/54	0.	0.
	OA	1/48	12/53		6/51	12/53	2.5	0.4
NIKE-HERCULES	R	10/53	10/56	4/52	6/53	6/60	7.0	2.3
	D	10/53	10/56		6/56	6/61	5.0	1.7
	T	10/53	10/56		6/57	6/61	4.0	1.3
	OE[2/]	6/54	10/56		6/59	6/62	3.0	1.3
	OE[2/]	6/54	10/56		6/59	6/57	—	—
	OA	12/53	6/57		12/57	6/58	0.5	0.1
TALOS (land-based)	R	—	—	9/54	—	—	—	—
	D	6/54	10/55		6/57	6/57	0.	0.
	T	6/54	10/55		6/58	6/58	0.	0.
	OE	—	—		—	—	—	—
	OA	12/54	6/57		12/59	6/60	0.5	0.2
HAWK I	R	10/53	10/54	3/51	6/54	9/54	0.2	0.2
	D	10/53	10/56		6/56	3/58	1.8	0.6
	T	10/53	10/56		6/57	7/59	2.1	0.7
	OE	10/53	10/56		6/58	1/61	2.6	0.9
	OA	3/51	6/57		6/56	10/59	3.3	0.5
PLATO	R	10/53	10/56	9/52	6/57	6/63	6.0	2.0
	D	10/53	10/56		6/58	6/63	5.0	1.7
	T	10/53	10/53		—	—	—	—
	OE	10/53	10/53		—	—	—	—
	OA	6/56	6/57		12/63	—	—	—

1/ R = Research, D = Development, T = Test, OE = Operational Evaluation, OA = Operational Availability.
2/ Two dates are shown in the basic data. Both are indicated here.

Appendix B

EXPLANATION OF PLOTTING METHOD USED IN SECTIONS IV AND VIII

The figure below illustrates the graphical plotting method shown in Sections IV and VIII. The dates on which estimates of future specified events (e.g., "operational availability") are made are plotted on the ordinate, and the corresponding estimated dates for completion of those specified events are plotted on the abscissa.



For example, point 1 (B) represents an estimate of operational availability. The date the estimate was made was mid-1945 (ordinate) and the estimate stipulated that operational availability would be achieved in the middle of 1948. Points 2, 3, and 4 are additional points representing estimates of operational availability. Point 4 (D), which falls on a line 45 degrees from either axis, represents the actual date of operational availability. Points on the "45-degree line" can be visualized as representing the present as of any date of estimate; points (such as points 1, 2, and 3) which lie to the right of the 45-degree line refer to the future; points which lie to the left of the 45-degree line relate to the past.

Further information available from this plot is:

(1) AC - actual time-to-go as of the date of the first estimate.

(2) AB - estimated time-to-go based on the first estimate.

(3) BC - error of the first estimate.

(4) CD - period of time over which estimates are made.

(5) $^{BC}/CD$ - average slippage rate from first estimate to operational availability.

Appendix C

METHOD OF COMPARING ESTIMATING PERFORMANCE IN OPERATIONAL AND NONOPERATIONAL SYSTEMS

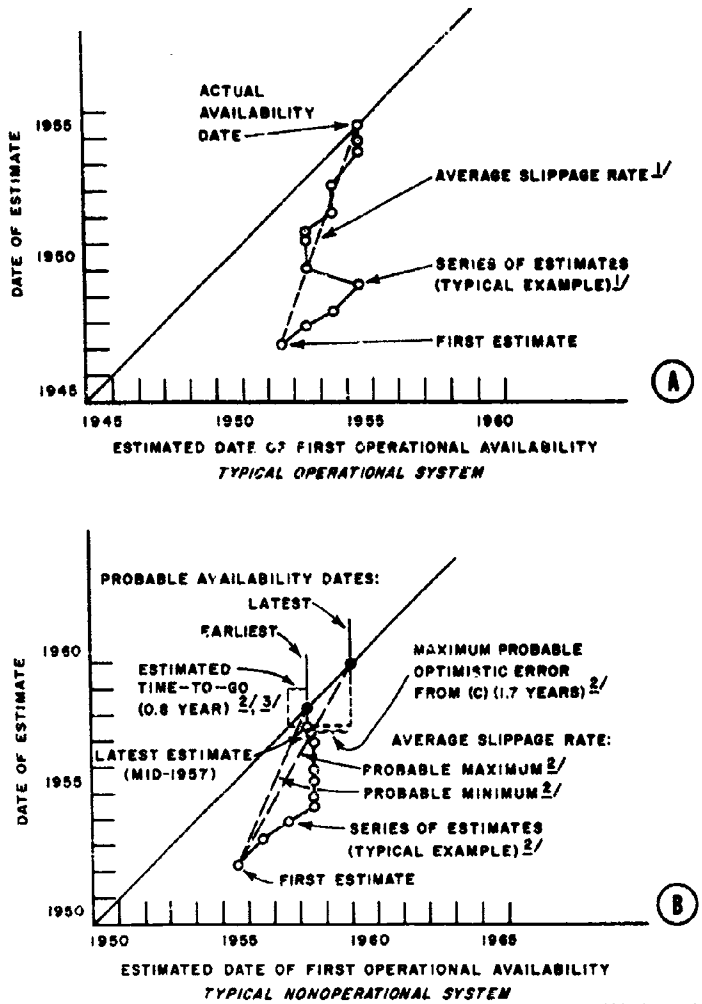
It was necessary to compare the estimating performances for nonoperational systems with those for operational systems to see if substantial differences exist which could be taken into account in interpreting the data for nonoperational systems.

The measure of comparison chosen was the average slippage rate (see Appendix B). The average slippage rate, as defined, appears to represent the data adequately for the purpose, and is simple to determine.

Figure 16 illustrates the method. For operational systems, Figure 16 (A), a line is drawn from the first estimate to the operational availability point and its average slippage rate determined in terms of years' delay per year.

For nonoperational systems, Figure 16 (B), earliest and latest probable availability dates were determined and the rates of change from the first estimate to these two points were measured. An earliest and latest probable date was chosen to describe the estimating performance rather than a single "most probable" date to call attention to the uncertainty of the extrapolation.

The earliest and latest probable availability dates were established on the assumption that the errors of mid-57 estimates for the nonoperational systems would follow the pattern of the errors for the operational systems shown in Figure 4. Figure 16 (C) shows the band which includes 80 percent of the data points of Figure 4 (excluding the 10 percent of the points with the greatest optimistic error and the 10 percent with the least optimistic error). The lines of probable maximum and probable minimum optimistic error, used to project the earliest and latest probable availability dates, are simplified approximations of the edges of this band. Hence, the probable earliest and latest availability dates can be expected to bound the actual date of operational availability in about 80 percent of the cases, if the estimating accuracy of these nonoperational systems follows the pattern of the operational systems.



1/ Typical example used: SPARROW I. Average slippage rate = 0.35 year's delay/year.

2/ Typical example used: REDSTONE. Average slippage rate:
Probable minimum = 0.47 year's delay/year.
Probable maximum = 0.58 year's delay/year.

3/ See Appendix B

FIG. 16

ILLUSTRATION OF COMPUTATION OF AVERAGE RATES OF CHANGE OF ESTIMATED OPERATIONAL AVAILABILITY

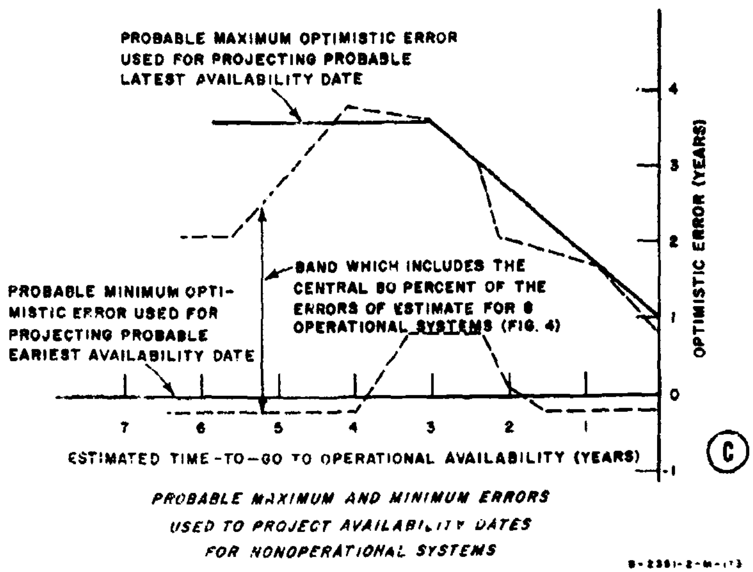


FIG. 16 (Continued)

ILLUSTRATION OF COMPUTATION OF AVERAGE RATES OF CHANGE OF ESTIMATED OPERATIONAL AVAILABILITY

Figure 16 illustrates the method of measuring average slippage rate. The plot of estimates for a typical operational system, SPARROW I, is shown in Figure 16 (A). The average slippage rate, from first estimate to the actual availability date (0.35 year's slippage per year), is obtained by dividing the total slippage (the horizontal distance from June '52 to April '55, or 2.8 years) by the time from the date of the first estimate to the availability date (the vertical distance from March '47 to April '55, or 8.1 years).

The plot of estimates for a typical nonoperational system, REDSTONE, is shown in Figure 16 (B). The latest estimated availability date is March '58 which is 0.8 year estimated time-to-go from June '57, the date the estimate was made. Probable minimum and maximum optimistic errors associated with an estimate of 0.8 year time-to-go are obtained from Figure 16 (C): zero years probable minimum and 1.7 years probable maximum optimistic error. The earliest and latest probable availability dates are determined by applying these allowances for error in Figure 16 (B): the earliest probable date is March '58 plus 0.0 year, and, the latest probable date is March '58 plus 1.7 years (20 months), or November '59. These projected earliest and latest probable availability dates are used in measuring the average slippage rate in the same manner as described above for the typical operational system.

STANFORD RESEARCH INSTITUTE

MENLO PARK, CALIFORNIA

REGIONAL OFFICES AND LABORATORIES

SOUTHERN CALIFORNIA LABORATORIES
820 Mission Street
South Pasadena, California

SOUTHWEST OFFICE
3424 North Central Avenue
Phoenix, Arizona

PACIFIC NORTHWEST OFFICE
421 S. W. 6th Avenue
Portland, Oregon

WASHINGTON OFFICE
711 14th Street N. W.
Washington, D. C.

EUROPEAN OFFICE
Pelikanstrasse 37
Zurich, Switzerland

HAWAII OFFICE
195 South King Street
Honolulu, T. H.

NEW YORK OFFICE
60 East 42nd Street
New York 17, New York